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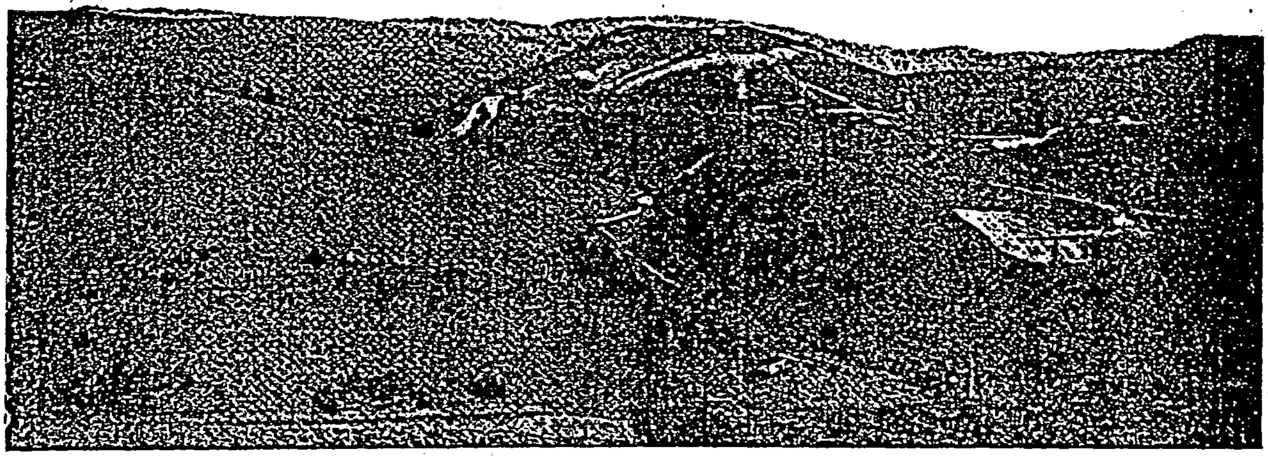
MEMOIR No. 2[illegible]

TALC, GRAPHITE, VERMICULITE AND ASBESTOS IN MONTANA

MONTANA SCHOOL OF MINES
BUTTE, MONTANA

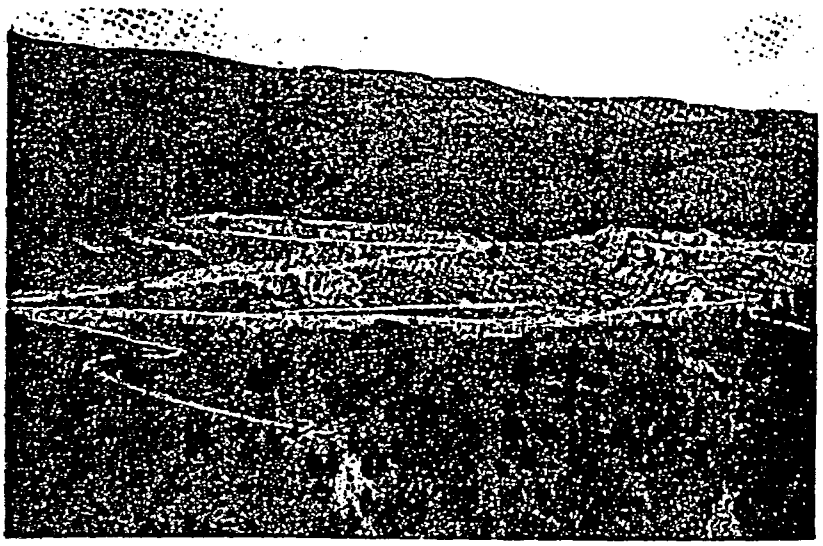
A. VIEW OF SMITH-DILLON TALC MINE

B. VIEW OF CRYSTAL GRAPHITE MINE



C. VIEW OF JOHNNY GULCH TALC DEPOSITS

D. VIEW OF KARST ASBESTOS PIT



E. VIEW OF LIBBY VERMICULITE DEPOSIT

STATE OF MONTANA
BUREAU OF MINES AND GEOLOGY
Francis A. Thomson, Director

Memoir No. 27

TALC, GRAPHITE VERMICULITE AND ASBESTOS DEPOSITS IN MONTANA

By
Eugene S. Perry

MONTANA SCHOOL OF MINES
BUTTE, MONTANA
1948

FOREWORD

Illustrative of the development of the non-metallic mineral resources of Montana are the talc and graphite mines southeast of Dillon, the talc mines south of Ennis, and the vermiculite mine northeast of Libby. The success of these operations, and the production of other non-metallic minerals in Montana such as gypsum, points to an ever increasing development of this phase of the mineral industry in the state which in the past has yielded in the neighborhood of $100,000,000.

Talc and the other minerals described under this cover are not directly related to one another, however this report is the beginning of a series in which it is intended all known non-metallic mineral resources of Montana will be described. Kyanite and sillimanite are described. in Miscellaneous Contributions No. 10. Other nonmetallic resources are phosphate,bentonite, gem stones, and optical calcite; and of course the production of lime, cement, and stone is the basis of important industry.

Montana is noted for its large production of metals such as gold, silver, lead, zinc, manganese, and in particular copper. Mining of these resources has been continuous for over 80 years, and has yielded a return of over four billion dollars. The lure of metal mining has over-shadowed the mining of these less glamorous materials, notwithstanding their vital importance to industry in general. It is hoped that the publication of information pertaining to the non-metallic mineral resources will aid in their development.

Francis A. Thomson
Director

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TALC, GRAPHITE VERMICULITE AND ASBESTOS DEPOSITS IN MONTANA

By

Eugene S. Perry

PART I. TALC

General considerations

The mining of talc has been carried on in Montana for about six years, and this mineral is now being produced in commercial quantities 11 miles southeast of Dillon and 20 miles south of Ennis. Deposits are known at several other localities in southwestern Montana, and some of them may be workable.

Talc is a hydrous silicate of magnesium. It is characterized by its extreme softness and its soapy feel. In color it is light-gray to white, and some varities have a greenish tinge. In texture it is commonly too fine grained for individual particles to be easily observed and it may resemble soap, but it may also be micaceous or foliated with flakes or fibers visible to the unaided eye. The name steatite may be applied tothe pure compact microcrystalline types. Soapstone is a rock containing 50 to 75 percent of the mineral talc together with rock impurities, and it is not known to occur in commercial deposits in Montana. To be of commercial grade soapstone should be of such a character that it can be cut or sawed into thin slabs such as are used for table tops in chemical laboratories or in electrical switch boards, and the slabs or panels should be free of incipient fractures, cracks, or breaking planes. Serpentine, which resembles talc, and which also occurs southeast of Dillon, is considerably harder than talc.

The commercial value of talc lies in its soft character, its chemical inertness, its ability to be finely pulverized with ease, and its ability to mix readily with other ingredients when finely powdered. Also it has the ability to be "burned" or baked, with or without binder, and with low shrinkage. It forms a porcelain-like product with low heat and electrical conductivity. In burning a chemical change takes place.

Deposits of common talc are relatively plentiful in the United States and foreign countries, and supply exceeds demand; hence competition within the industry is keen and prices are held to a relatively low margin of profit. The largest volume is used in ceramic products. Exceptionally high grade of pure talc is used in manufacture of cosmetics, and special varieties (such as "lava" talc) are used in making radio-tube insulators; such varieties bring premium prices. Cost of transportation is an important item in the sale of the ceramic grades of talc, and Montana is a long distance from markets. United States production of talc and soapstone in 1937, an average pre-war year, was 230,000 tons valued at $2,562,000, or slightly over $11 per ton.

About 90 percent of the talc marketed in United States is pulverized before sale. It is used in the manufacture of certain paints (48%), paper (16%), roofing materials (11%), rubber (11%), toilet powders (3%), foundary facings, ceramic products, and many other products. Only the finest and purest grades are used in toilet powders, lotions, and face cream. An unusual variety, known commercially as "lava" talc, can be machined into intricate shapes in crude form, burned into a finished product resembling porcelain without change in shape or size, and in this form it is used as an insulator and spacer in vacuum tubes and electrical instruments. It is said that there is no satisfactory substitute, and also that the Montana material is superior to imported material which has supplied most of the market. Ceramic (common), cosmetic, and lava talc all have been mined and marketed from Montana.

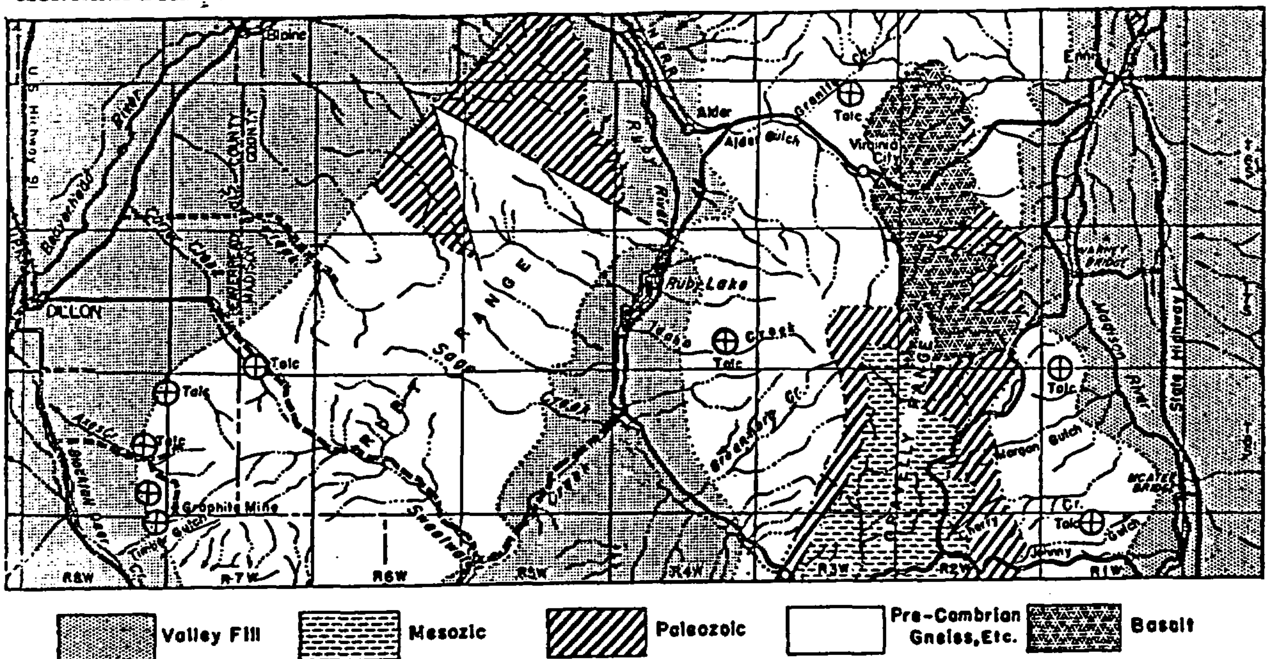
General Geology

Geologically, in Montana talc is known to occur only in rocks of two geologic ages. A small vein-like deposit about one mile south of Helena was developed in dolomite of the Pilgrim formation of Cambrian age. This deposit has been practically worked out, but it is of much geologic significance. The largest deposits occur in dolomitic marbles in the Cherry Creek series of early pre-Cambrian age in a region 40 miles across extending from Madison River valley near Ennis to Blacktail Deer Creek valley near Dillon. (See Plate 2, A). The two commercial mines now operating on Axes Creek southeast of Dillon and on Johnny Gulch south of Ennis are in this area. Other deposits in this area are on Timber Gulch and Carter Creek near Dillon and Granite Creek and Idaho Creek near Virginia City. Minor occurrences of talc have been observed in several other localities, and in a few places opened by pits. It may be exptected that minor amounts of talc may be found in the marbles of the Cherry Creek series almost anywhere in this area, although it is not likely that large commercial bodies are present and have been overlooked.

The Cherry Creek series, named by Peale in 1896 from a creek by that name 20 miles south of Ennis, is a most intensely metamorphosed series of early pre-Cambrian schists, phyllites, light- and dark-colored gneisses, amphibolites, schistose quartzites, and coarsely crystalline marbles, locally containing garnet, staurolite, kyanite, sillimanite, and similar minerals. The thickness has not been measured accurately, but it probably is in the order of four to six thousand feet. Individual beds of characteristic rock types from a few inches to several feet in thickness may be distinct and well defined, and the thicker units may be traced in outcrop for several miles. The series is definitely of sedimentary origin, but it has been intruded by dikes and sills some of which are metamorphosed. Both major and minor folding are prevalent, and in some places folding is isoclinal or overturned. Crumpling of beds is common.

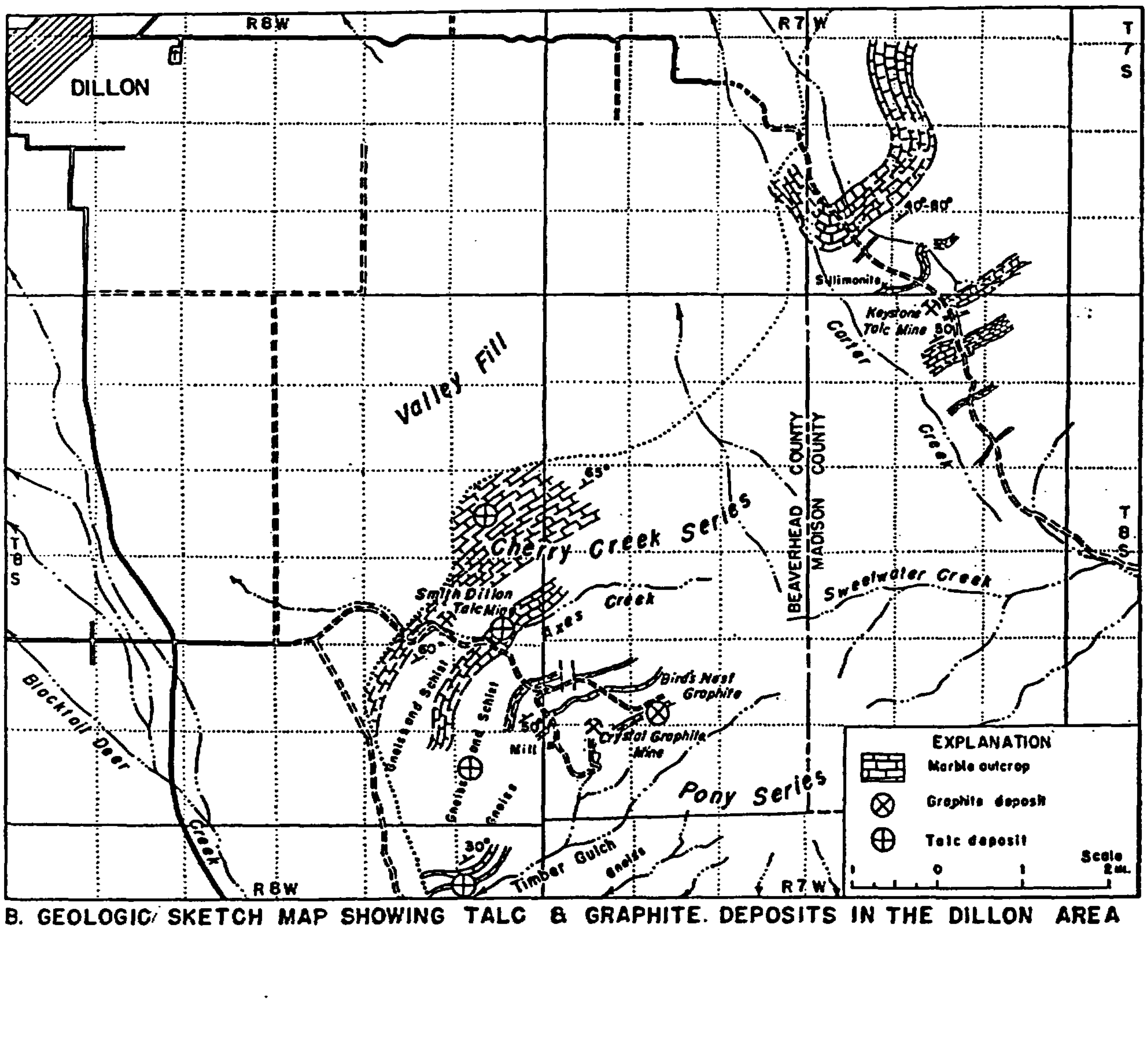
Of particular interest in talc prospecting are the zones of marble in the series. As observed on Axes Creek, at least six marble members are present, and some are 400 to 800 feet or more in thickness. The amount of marble to be observed in the series decreases eastward, and members of the series cannot readily be correlated between Dillon and Ennis. Because of the abundance of the marble in the series on Axes Creek it is suggested that the rocks in this area be called the Axes Creek phase of the Cherry Creek series, and that the name Cherry Creek be retained for these rocks over the entire region. A detailed study of this series of rocks is being made by E. W. Heinrich for Montana Bureau of Mines and Geology during 1948.

This complex series of rocks, known to be present in a region 75 miles or more across underlies folded Cambrian strata. The Belt series of late pre-Cambrian age is absent in this part of Montana, but as determined by degree of metamorphism, it is very much younger than the Cherry Creek series. The base of the Cherry Creek is in question. Commonly at the base is a highly metamorphosed series of feldspar gneisses in which crumpled bands are conspicuous. This gneiss series could be metamorphosed sediments older than Cherry Creek, but more likely



A. GEOLOGIC SKETCH MAP OF AREA BETWEEN DILLON AND ENNIS

After U.S.G.S. Geologic Map of Montana, 1944



B. GEOLOGIC SKETCH MAP SHOWING TALC & GRAPHITE DEPOSITS IN THE DILLON AREA it is a metamorphosed mass of igneous rock such as granite which was intruded into the Cherry Creek prior to its intense regional metamorphism. The term Pony series is commonly applied to the gneiss series.

Talc is believed to have originated by the action of hydrothermal (hot water) solutions acting upon magnesium-bearing rocks through which the solutions passed, the process having occurred when the rocks were deeply buried. Talc is not believed to form by action of the surface waters. Elsewhere than Montana talc occurs in dark-colored igneous rocks and gneiss as well as in crystalline dolomitic marble, but no occurrences of importance other than in marble are known in Montana.

The Dillon, Ennis, and intervening talc deposits are all similar in general occurrence. Small vein-like bodies one-quarter inch to 2 or 3 inches thick locally appear in the marble, extend 1 to 5 feet and then cease. Large bodies, which may be in the order of 50 feet wide and 300 feet long, are irregular in shape and cease to be vein-like. Most of the bodies lie parallel to the original bedding, traces of which show in the marble, but they may also cut across bedding planes. In large talc bodies, blocks or cores of unaltered marble may lie within and be entirely surrounded by talc. Practically all contacts between talc and marble are sharp. Disseminations, noticeable in hand speciman, of talc in marble or marble in talc are seldom observed, although microscopic studies show talc disseminated in marble. Impurities, essentially unaltered rock, may be present in the talc locally.

Some deposits are unusual in that crystalline graphite in parallel flakes as much as one-eighth inch across are thickly dispersed through the talc, the alinement being parallel to that of the talc body and the bedding of the marble. Other deposits appear to have contained pyrite, the evidence of which now consists of limonite (iron oxide) scattered through the talc in small lumps or pseudomorphous crystals after pyrite. Silicate minerals such as tremolite are so rare as not to be commonly observed with the unaided eye. Graphite, limonite, or rock impurities in some Montana talc makes it unsatisfactory for industrial use, however many large bodies of talc are completely free of these impurities.

Talc Deposits East of Dillon

Location and topography: The largest production of talc in Montana comes from a deposit on Axes Creek, 11 miles southeast by road from Dillon, the nearest shipping point. A large body of massive talc near creek level has been opened by the Tri-State Minerals Company of Los Angeles by means of an open cut, adits, a winze, and drifts at a lower level. During 1946 approximately 5,000 tons of broken but uncrushed talc were marketed. This company also has opened deposits on Carter Creek seven miles northeast, and on Timber Creek two and one-half miles southwest from the Axes Creek deposit, and has investigated other deposits in southwestern Montana. Commercial shipments have been made only from the Axes Creek deposit by this company. (See plate 2, B.)

Dillon, population about 3000, is the county seat of Beaverhead County and the largest city in this part of Montana. Farming and stock raising are the principal industries, but considerable metal mining is also carried on in the vicinity. The city is serviced by a branch line of the Union Pacific Railway extending from Salt Lake City to Butte, and an oiled highway, U. S. 91. Fair to good roads radiate into the surrounding mountains and valleys. The altitude of Dillon is 5090 feet above sea level.

The topography of this region is characteristic of that of western Montana wherein high rugged mountain ranges trending north to south are separated by broad relatively level valleys containing hundreds of feet of lake and alluvial material is not crushed or milled, although hand-sorting is practiced to remove blocks of limestone or impure material. The talc is washed to remove clay impurities before being hauled by trucks to Dillon, from which point it is shipped to Ogden, Utah, for further treatment before being marketed.

Carter Creek Deposit: The deposit on Carter Creek, known by the operators as the Keystone mine, is eight miles northeast of the Axes Creek deposit, and 13 miles east of Dillon by roads easily traveled in dry weather. (See plate 2). It is low in the foothills of the range, and lies in one of the marble members of the Cherry Creek series as does the Axes Creek deposit. Metamorphosed quartzite is not associated with the marble as it is on Axes Creek. Exposures of the irregularly-shaped deposit of talc are in an area about 450 feet long and about 100 feet wide; and a shaft 60 feet deep, together with over 300 feet of drifts at its bottom are all in talc (fig. 1). Several small separate bodies of talc lie to the northeast and southwest within 500 feet, and veinlets and irregular masses a few inches thick and a foot or two long are scattered through much of the marble member which appears to be about 600 feet thick. The irregular deposit, although in part parallel to bedding in the marble, also cuts across bedding locally, and it appears to have a northwesterly plunge across bedding and beneath surface exposures of marble. The marble dips about 50° NW. Dolorite dikes perhaps 25 to 50 feet thick cut the marble in this locality.

The talc, which is light-gray, dense, and fine-grained, is of good quality, but contains many small lumps of limonite (iron oxide) apparently altered from pyrite scattered through the body. Some graphite occurs sparingly in the talc. The presence of limonite, which cannot be separated in mining, yields a color to the pulverized product causing it to be less satisfactory for uses where a pure white talc is desired, and the deposit has not been worked for the market. The deposit is, however, a large potential reserve of commercial talc suitable for many uses.

Timber Gulch Deposit: The Timber Gulch deposit, known by the operators as the Crescent mine, is three miles south of the Axes Creek deposit. (See plate 2). It is accessible by automobile on a dirt road which branches off the road to the Axes Creek deposit and follows southward along the main valley. It lies near the margin of the valley-fill of Blacktail Deer Creek at the foot of the mountain slope. Two members of impure marble, 10 to 15 thick and separated by about 150 feet of micaceous gneiss, have locally been replaced entirely or in part by talc. Intermittent exposures of talc may be followed for 800 to 1,000 feet along the strike of the marble, which dips northwesterly at about 50 degrees. A shallow inclined shaft and pits expose the talc to a depth of 10 to 20 feet. The marble is much decomposed locally, and may appear as a brownish friable rock which can be crumbled in the hand. Massive pegmatite dikes occur close by.

The deposit is unusual in that disseminated through the talc are thin flakes of crystalline graphite up to one-eighth inch across, the quantity of graphite in places amounting to perhaps one-half of one percent. The flakes lie parallel to one another, and to the bedding of the marble, and the individual flakes are distinctly separated from each other. Flakes of graphite and grains of talc and other silicate minerals are disseminated in the marble. The talc itself is gray and fine-grained, and of a commercial quality, but the presence of graphite in the talc has caused the abandonment of the deposit, at least for the present time.

TALC DEPOSITS SOUTH OF ENNIS

The talc deposits 20 miles south of Ennis lie about 4 miles from State Highway No. 191, up Johnny Gulch in the low foothills on the east side of the Gravelly Range. (See plate 2, A). Ennis is a small town with population of about 400, but the nearest shipping point is Norris, population about 75, which is at the end of a branch line of the Northern Pacific Railway about 35 miles north of Johnny Gulch. State Highway 191, which passes through Norris and near Johnny Gulch, is a modern oil-surfaced road, readily traveled throughout the year. The road from the highway up Johnny Gulch to the talc deposits crosses Madison River on a steel bridge known as McAtee Bridge, and although essentially a dirt road may be traveled most of the year. Stock raising and some metal mining are the chief industries in this region. The altitude of Madison River valley is about 5000 feet, and of the summit road along Gravelly Range, 9000 to 9500 feet. Altitude of the talc deposit is between 5500 and 6000 feet.

Geology: The Gravelly Range is made up mainly of Paleozoic and Mesozoic strata bent into broad open folds by Laramide (Rocky Mountain) orogeny or mountain making. The pre-Cambrian metamorphic complex is exposed low in the foothills on the east side by erosion of overlying Cambrian strata. Along Madison River valley the metamorphic rocks are buried beneath alluvial and lake deposits. The uppermost pre-Cambrian Belt series, so widespread in northwestern Montana, is absent in this region.

The metamorphic rocks, named the Cherry Creek series after the first creek north of Johnny Gulch, are somewhat different from those on Axes Creek, not only in lithologic character, but also in the sequence of the various members. They consist of light- and dark-gray gneisses, mica schists and phyllites, schistose quartzites, and dolomitic marbles, and excellent exposures of the series show in bands which have a general northeasterly strike. Although as previously stated the series is of sedimentary origin, metamorphism has proceeded so far that all original sedimentary minerals are changed to metamorphic minerals, and sedimentary structures such as ripple marks have completely disappeared. Crystals (metacrysts) of garnet, staurolite, kyanite, and similar minerals are plentiful in the gneiss and schist, and in places may constitute one-fourth of the rock. Deposits of kyanite (aluminum silicate) associated with pegmatite in the gneissic area six miles north of Johnny Gulch are potentially commercial. The beds of the Cherry Creek series have been closely compressed by folding; dips are commonly more than 60 degrees, and in many places bedding stands nearly vertical. An area of gray gneiss south of Ruby Creek probably corresponds to the Pony series.

Marble appears in several bands striking across the area, but there may be repetition by folding. The largest area of marble, and the area in which the commercial deposits of talc lie, is between Johnny Gulch and Cherry Creek; it is about 5 miles long in the direction of the strike of beds and 1½ miles wide. The rock weathers to dirty brown granular surfaces which look dark in the distance. Due to its resistance to weathering it forms a conspicuous ridge known locally as Black Point, extending perhaps half a mile into Madison Valley. For this reason the marble has been called the Black Point dolomite, however the writer feels it is better not to name members in the Cherry Creek series permanently until the sequence, thickness, and character of the various units are determined. Bedding in the marble at Black Point stands nearly vertical, and the writer is of the opinion that the one and one-hald mile width of the area results from repetition of beds either by faulting or folding.

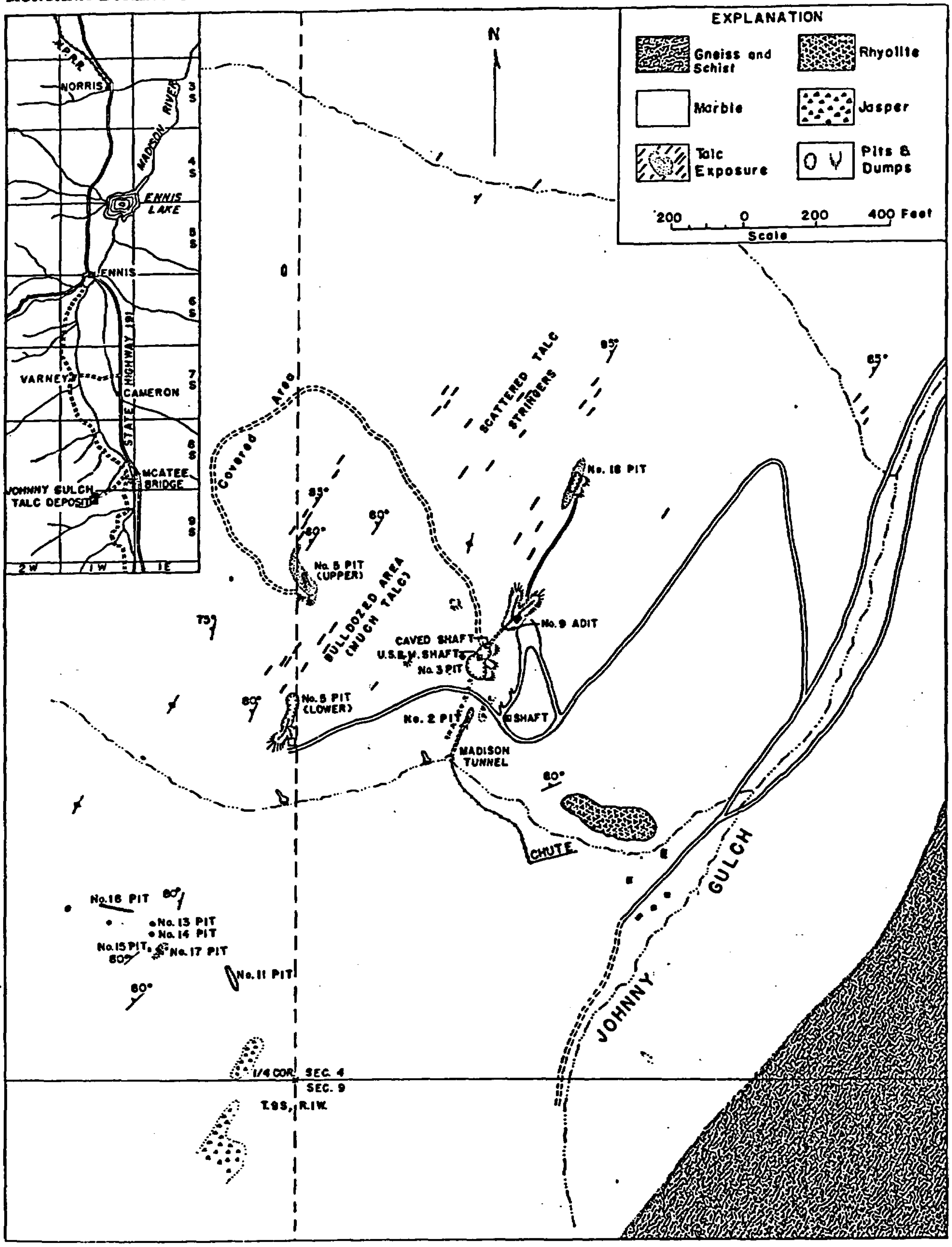
Talc in minor quantity has been observed in the areas of marble other than Johnny Gulch, and one deposit about $1\frac{1}{2}$ miles north of Morgan Gulch was opened by a shallow shaft and pits sunk by the Tri-State Minerals Company. It was abandoned because of low grade and lack of quantity. Small local deposits of manganese oxide, worked during World War I, are present in several of the marble areas. On Cherry Creek such a deposit contained much hematite (iron oxide). These minerals are apparently superficial. Metalliferous mineralization is present as veins in the gneisses and schists, but no commercial mines have as yet been developed.

Evidence of igneous activity, other than pegmatite dikes and late lava flows, has not been observed in the area. Probably dikes or sills are present, but the nearest observed large mass of intrusive igneous rock is the Tobacco Root batholith about 25 miles north of Johnny Gulch near Norris. Basalt flows cap parts of the crest of the Gravelly Range, and small patches of rhyolitic lava rest on the metamorphic complex in several places. Some of the rhyolite is within the talc-bearing area.

Johnny Gulch Deposits: The talc deposits on Johnny Gulch (See plate 4) occur as isolated bodies in relatively pure marble over an area at least 2000 feet long and 800 feet wide, and talc may lie beneath a soil covered area immediately west. Showings of talc also occur $1\frac{1}{2}$ to 2 miles west of the deposits now being worked. In the area being mined, five or six bodies opened by cuts and adits are 100 to 150 feet long and 25 to 50 feet wide, and many smaller bodies are present. Almost innumerable small masses or veinlets of talc appear and disappear abruptly in the marble of the talc-bearing area. All the bodies tend to be elongated in the direction of strike of bedding in the marble, but the larger bodies are irregular in shape, and in part may cut across bedding. The bodies appear to continue vertically in depth, however bedding in the marble dips at angles ranging from 80 to perhaps 88 degrees. Probably the deposits cease in the vertical dimension as rapidly as in the horizontal. Pits, trenches, shafts, adits, and underground workings, numbered up to 18, have been sunk into the larger deposits, and many unnumbered pits have been dug. In places the thin soil covering has been removed by bull-dozer cuts.

The talc differs somewhat in appearance from place to place, and different grades are classed as ceramic, cosmetic, and lava. The difference between ceramic and cosmetic appears to be a matter of purity, or color, but lava talc apparently owes its peculiar properties to some physical condition within the talc, possibly a permeability. That type called cosmetic commonly occurs in concretion-like masses up to 6 or 8 inches in diameter with interior radiating talc structure, these concretionary masses lying within a body of massive talc. Most of the talc is massive and so fine-grained as to resemble soap in appearance, but some is granular or micaceous. That type known as lava generally has dendritic (fern-like) growths of black manganese oxide reaching into the talc from fracture planes in most intricate and pleasing patterns, but some lava talc is without dendrites. Colors of the talc range from white through light-gray to dark-gray, but commonly greenish or bluish tinges appear. Crushed zones within the talc are present. Some talc shows an indistinct banded structure in tones of gray, the darker gray resulting from microscopic black specks, possibly iron oxide or carbon. In some places this banding is crumpled similar to drag folds, a condition which the writer believes is residual from pre-existing marble which has been replaced by talc. (See plate 7).

The lava grade talc, which occurs mainly in pit no. 9 but also in other places nearby and on the Queen Claim $1\frac{1}{2}$ miles westward, is associated with much powdery and compact iron oxide and some manganese oxide in a thick mantle of soil and weathered rock. Solution cavities containing oxide material extend



MAP OF JOHNNY GULCH TALC DEPOSITS, MADISON COUNTY downward into the marble. It appears that the development of this type of talc is related to intense conditions of weathering since the original talc deposition, and it is possible that the presence of the iron and manganese oxides have some bearing on its development. Chemical composition of lava talc from pit 9, and ceramic talc from other pits is not materially different as shown by the following analysis.

Analyses of Talc (U. S. Bur. Mines)

	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	Na_2O	K_2O
Pit 5	61.70 %	1.29 %	1.55 %	Tr.	32.44 %	0.37 %	0.46 %
Pit 7	61.29 %	1.36 %	1.34 %	Tr.	31.26 %	.26 %	.33 %
Pit 9	61.76 %	1.33 %	1.51 %	Tr.	31.95 %	.27 %	.32 %

Walls of the larger bodies of talc are irregular and may show bowl-shaped bulges or recessions in the marble. Also "ribs" of marble may be present within the body of talc, however, silicate minerals other than talc are seldom observed, at least with unaided eye. Coarsely crystalline calcite, both white and colored, occurs locally. Jasper (a brown fine-grained iron-bearing variety of quartz) is plentiful in irregular and vein-like masses paralleling strike of beds in the central part of the area. Although within a few feet of talc bodies, there is no apparent relationship. Much jasper is also present at the southern end of the area where it appears to occur as irregular masses replacing marble.

The Johnny Gulch deposits were discovered by Lewis Clark on his homestead shortly after the turn of the century, and later were opened by shallow pits, In 1942 L. F. Teutsch obtained a lease on the property, and, operating under the name of Mountain Talc Mines, carried on exploration by digging larger pits and driving adits into exposures of talc. The "lava" grade talc was soon recognized by eastern consumers, and with war-time demand for this important material, development proceeded rapidly, in part by aid of the U. S. Bureau of Mines. Commercial quantities of the lava talc were found only at the one locality known as Pit No. 9, and exploratory work as well as mining was concentrated on this deposit. A 240-foot adit, known as Madison tunnel, was driven by the Tri-State Minerals Co. into the hill slope so as to cut the deposit about 80 feet beneath the surface. Soon after a 75-foot shaft was sunk through the out-crop of talc by the U. S. Bureau of Mines, and drifts driven at its bottom. Lava talc was found at depth in narrow vein-like bodies cutting fresh marble, but it could not be mined without shattering, and hence could not be produced commercially.

Early work was concentrated on the lava grade talc, and the first shipment of 4000 pounds sent by express to the American Lava Corporation of Chatanooga, Tenn., was made in December 1942. In the fall of 1943 and spring of 1944, while exploratory work was being carried on, it is reported that 37 tons of the critical mineral was mined and shipped during the winter, and 90 tons during the following spring. Shipments have continued from time to time.

Although large quantities of ceramic talc are present, only a relatively small amount of this material has been shipped, largely due to distance from railroad and low value. The variety classed as cosmetic talc has been shipped as supply and market demand permitted. Information is not at hand to calculate total reserves, but it is believed that many thousands of tons of ceramic talc is available for mining, and much is present in mine dumps.

Mining has been mainly by open cut methods, although short adits have be driven. The Bureau of Mines 75-foot shaft and drifts were driven largely for exploratory purpose, and although lava grade talc was present at depth, shipments of this grade came from the open cut near the collar of the shaft where larger blocks could be more readily obtained from weathered and disintegrated material. Pieces weighing 5 pounds or more are desired. The blocks were trammed from the pit to a sorting floor where they were classified largely by size and freedom from cracks, then hauled by truck to Norris. The operation requires much hand labor. Cosmetic talc is obtained largely by selective min in those portions of the deposits where this grade of talc is present. This variety is particularly plentiful in Pit 18. Ceramic talc was shipped from a large open cut and adit known as Lower Pit 5.

Other Talc Deposits in the Cherry Creek Series

Talc has been observed in the marbles of the Cherry Creek series of this region at localities other than those already described. (See plate 2-A). One about two miles up Granite Creek north of Virginia City occurs in a 65-foot marble member which dips southeast at 80 degrees. It is opened by a sho adit and shallow pits. Small stringers and replacement bodies of talc may be observed, and hand specimens of fairly good talc may be obtained; however, mo of the talc is impure, and talc of shipping grade in quantity is not exposed.

Another deposit is reported to be present southwest of Virginia City on Idaho Creek. The hand specimens of the talc are good, but as a whole the deposit is said to be small and the average material impure.

As is to be inferred from the preceding descriptions, prospecting for ta should be confined to areas of dolomite, dolomitic limestone, or dolomitic marble, in the proximity of igneous activity.

Talc Deposit South of Helena

The talc deposit south of Helena is about one-quarter mile south of the city limits at an old abandoned quarry from which rock was obtained for the manufacture of lime. In this early operation a mineral which would not burn to lime was recognized, but it is said that the mineral was not identified until years later. In 1935 Mr. James McKelvey of Helena, owner, began minin the deposit, and in the course of a year several hundred tons valued at $10 p ton were shipped to eastern markets. The deposit of visible talc proved sma and was soon exhausted, and with no new discoveries, operations ceased.

Geology: The talc appears to be a replacement along a fissure cutting massive dolomite of the Pilgrim formation of Cambrian age, total thickness o the dolomite being about 800 feet. Talc may be traced intermittently for 35 feet along the surface. Irregular vein-like bodies and small stringers rang in thickness from less than one inch up to six feet. Vertically a body may tend 12 feet or more. Dimensions of the largest stope driven in talc are: length 35 feet, width 6 feet and height 8 feet. In this stope the talc body dips steeply to the southeast, whereas the strata dip northeast 30 degrees. Prospecting has not been carried on to depth, and it is not definitely known additional bodies of talc underlie the present workings.

Within the talc, irregular masses of unreplaced dolomite from a fractio of an inch to a foot or more across are scattered irregularly, and locally t streaks of chalcedonic quartz are present in the talc. The walls are irregu and in places silicified. Although the talc-dolomite contacts may appear sh ly cut as seen in the ground, microscopic studies show gradation across such boundaries. In places limonite altered from pre-existing pyrite is present in the talc. The talc itself is characteristically white, and most of it is so fine-grained that it superficially resembles soap. In places the talc is coarse enough so that individual flakes up to 1/25 inch across may be seen in radiating clusters or small veinlets cutting finer-grained talc. Also the coarser material appears to be adjacent to the dolomite contacts. Under hand lens the flakes have a pearly luster.

The Cambrian strata in this locality are bent into large open folds, and faulting occurs locally. About one-half of a mile southward a diorite dike cuts the strata, and a short distance beyond is granitic rock of the Boulder batholith. Small intrusive stocks related to the Boulder batholith are present within one mile to the north. Age of the intrusives is late Cretaceous or early Tertiary. The sedimentary rocks throughout the area have been much altered by igneous action, and their appearance differs from that in regions unaffected by igneous activity. No pegmatite dikes have been observed in the vicinity of the talc deposits. This part of Montana has been one of the most important gold-producing areas in this state.

Unquestionably the talc is a replacement of dolomite, and it must have been developed by hot solutions escaping from below. An analysis of the Pilgrim dolomite from this locality shows 43.3 percent magnesium carbonate and 54.6 percent calcium carbonate, and this may be the source of the magnesium in the talc. Of interest are the age relationships, wherein the talc must have been developed in Tertiary time subsequent to the intrusion of the igneous masses. By inference this may have a bearing on the age of the other talc deposits in Montana near Dillon and Ennis.

PYROPHYLLITE NEAR ARGENTA

The talc-like mineral, pyrophyllite, has not been produced commercially in Montana, although deposits of it are known. A deposit which may be commercial in size and grade occurs one-half of a mile northeast of Argenta, 12 miles northwest of Dillon. It lies about 300 feet north of Rattlesnake Creek and about 50 feet higher in elevation, low down on the rolling hills which rise northward from the creek.

Pyrophyllite is a hydrous aluminum silicate so similar to talc that the two may not be easily distinguished, except by chemical tests. The presence of magnesium in talc and of aluminum in pyrophyllite distinguishes these two minerals.

Principal uses of pyrophyllite are in the ceramics industry wherein it is used as an ingredient in manufactured products similar to those made from talc. Hence it is a competitor of talc, but it has not entered into use as extensively, possibly because known deposits are not as plentiful or as well developed. North Carolina is the principal producer, although it also occurs in California. Value of crude material is not greatly different from that of ceramic talc, which in crude form ordinarily ranges from $10 to $20 per ton at the mines for good grades.

The Argenta deposit of pyrophyllite occurs as nearly vertical tabular bodies cutting granitic igneous rock. The mineral has developed by alteration in place of the original rock. There are no definite walls to the altered zone. Pyrophyllite is exposed in two large pits up to 15 feet deep in the altered zone, and it also shows elsewhere in an area about 200 to 400 feet across. In general, in this locality the igneous rock is relatively unaltered. However, bands of what appeared to be nearly pure pyrophyllite 2 to 4 feet across may be seen in the face of the pits. These bands are interspaced with bands of a somewhat impure material which has a sandy appearance. A sample of the more pure part of the pyrophyllite deposit when panned yielded 10 to 15 percent of milky quartz in grains up to 1/10 inch in diameter. The pyrophyllite is extremely fine grained. Practically no iron-bearing (black) minerals are present in the altered zones, but they show in unaltered rock.

The strike of the altered zones is nearly due north, but definite evidence of prominent fissure zones is obscure. The igneous body is a small local intrusion, somewhat stock-like in character, which cuts the argillites and quartzites of the Belt series of pre-Cambrian age. The age of the intrusive is no doubt late Cretaceous or early Tertiary, as are other intrusive masses in this general region. Metalliferous deposits, particularly those of gold, silver, and lead, are plentiful near Argenta where mining began in about 1865, and has been carried on intermittently since that time.

The future of this pyrophyllite deposit would seem to depend on the initiative of local promotors, the quality of material which can be produced in shipping quantities, and the market demand. The presence of large commercial deposits of a good grade of talc in this part of Montana, which are being efficiently operated, detracts from the possibility of the present successful development of the pyrophyllite..

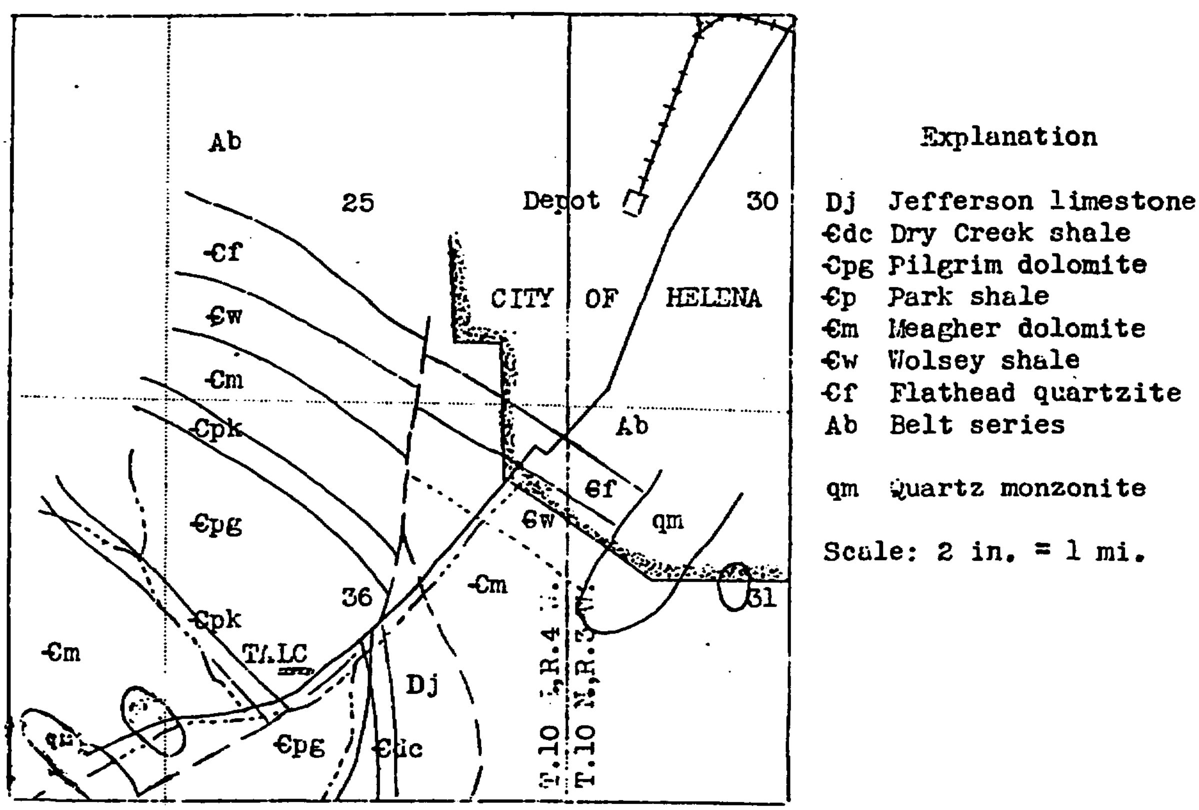


Figure 2.--Map showing location of talc deposit south of Helena.

PART II. GRAPHITE

General Considerations

Crystalline graphite of a quality equal to that imported into the United States from Ceylon occurs in commercial deposits southeast of Dillon. About 2,200 tons of concentrates have been marketed. Dillon, with a population of about 3,000, is the county seat of Beaverhead County. It is on a branch line of the Union Pacific Railroad, and also on U. S. Highway No. 91. It is the principal city in southwestern Montana where agriculture, cattle raising, and mining are the chief industries.

Crystalline graphite, which is pure carbon, is one of the most easily identified minerals because of its extreme softness, and the black streak or mark it makes when rubbed on paper. It occurs in shining black flakes and grains from microscopic sizes up to crystalline lumps one-half inch or more in length. It may be confused with molybdenite (molybdenum sulphide) but that mineral reacts vigorously when heated with nitric acid whereas graphite is inactive. Furthermore molybdenite has a bluish tinge of color. Amorphous carbon (Graphite) is dull and earthy, resembling soot from a stove.

Graphite is used in the manufacture of metallurgical crucibles and related products, special kinds of batteries, electric brushes and other electrical equipment, graphite paints, and certain types of lubricants. Some graphite is used in foundry facings, and there are many other uses. Graphite of various grades is produced in many countries. It occurs in many states of the United States and is produced in several. The total demand is relatively small, and in normal times about equals the supply. The price of crystalline graphite ordinarily ranges from $80 to $200 per ton (4 to 10 cents per pound), but during war-time demand, prices have been much higher.

In normal peace-time years, production of natural graphite within the United States will average about 2,000 to 3,000 tons per year each of crystalline and amorphous grades. Crystalline graphite is valued at about $60 to $90 and amorphous grades about $14 per ton; however, United States production of natural graphite has flourished only in times of war when importation of high-grade foreign graphite has been greatly curtailed, and demand caused an increase in price of the domestic graphite. Imports into the United States normally are about 2,000 to 3,000 tons of crystalline flake, 6,000 to 8,000 tons of crystalline dust, and about 10,000 tons of amorphous graphite, with respective values averaging $90, $65, and $15 per ton. A substantial quantity of artificial graphite is manufactured. Commercial grades of natural graphite should contain not less than 85 percent carbon, and 90 percent or more is desired. Most of the imported amorphous graphite comes from Mexico, whereas the bulk of the imported crystalline graphite comes from France, Ceylon, and Madagascar.

Crystal Graphite Mine

The Dillon deposits lie near the head of Timber and Van Camp gulches high in the Ruby Mountains east of Blacktail Deer Creek at the end of a ridge known as Crown Point. A graded gravel road extends 7 miles south from Dillon along Blacktail Deer Creek to a good mountain road, easily traveled by automobile during dry weather, which continues 9½ miles to the mines. The western slope of the Ruby Range rises abruptly from altitudes of about 6000 feet in the main valley to 7500 feet at the mine. The range is cut by deep canyon-like gulches

2 to 5 miles long, and bold exposures of hard rock ledges are common. The top of the range is a rolling upland, a remnant of an ancient erosion surface which existed in Tertiary time.

The deposits were discovered in 1899 by Mr. Robbins, a prospector, and soon sold to Mr. Pearl I. Smith of Dillon who organized the Crystal Graphite Company in 1901. The first shipment of 50 tons made in 1902, came from the Bird's Nest claim which lies about one mile east of the main workings on the Groundhog Claim developed mainly in 1918. Between 1902 and 1920 about 2,000 tons of graphite concentrate are said to have been marketed intermittently, most of this production being at the time of the first World War when prices ranged from 14 to 28 cents per pound. In 1938 the land was surveyed, and a patent on the Groundhog claim was issued to Mr. Ralph Smith, son of Pearl I. Smith who died in 1937. The property was leased in 1941, and operations were renewed under new management. In 1943 and 1944 a 1050-foot adit 280 feet below the main workings was driven, and in 1944 a small flotation mill was erected to treat the run-of-mine rock and old dumps containing much fine graphite. About 150 tons of concentrate, valued at $120 to $200 per ton, f.o.b. Dillon, depending on grade, are reported to have been marketed during this last operation.

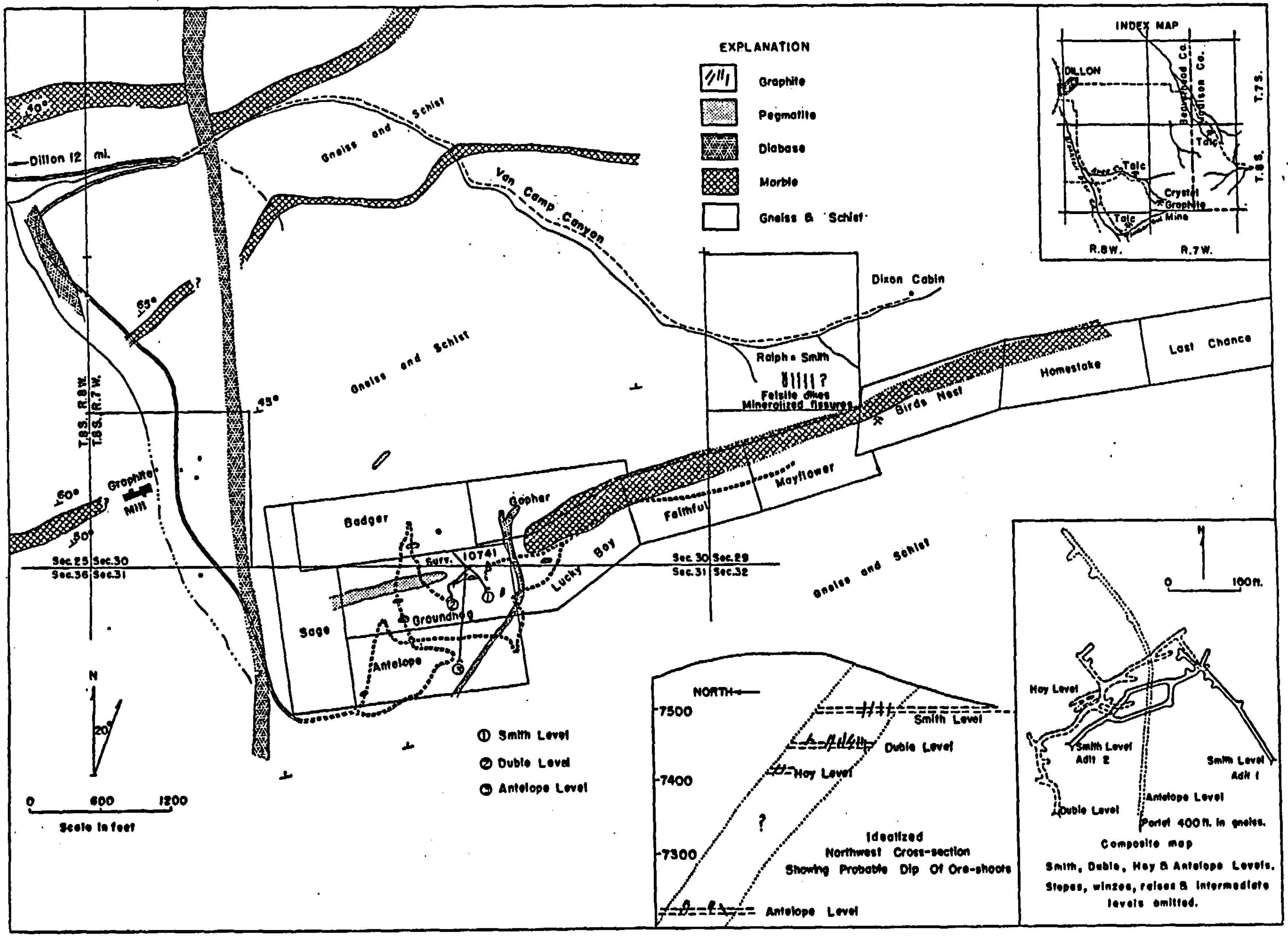
This part of the Ruby Range is composed of a complex series of gneisses, schists, and dolomitic marbles of early pre-Cambrian age. To the north of the graphite mines the metamorphic complex is definitely sedimentary in origin as evidenced by the presence of at least five marble members together with quartzite, which were originally limestone and sandstone. The series is considered equivalent to the Cherry Creek series* named after that locality south of Ennis. Some of the marble members are 600 to 800 feet thick, and are the host rock for commercial deposits of talc. The top of the series on Axes Canyon is obscured by Tertiary deposits, but not far distant middle Cambrian sediments overlie it. The Belt series of upper pre-Cambrian age is absent in this part of Montana. Apparently underlying the series is a great thickness of contorted feldspar gneisses which may correspond to the Pony series.** In general the Cherry Creek series on Axes Creek differs in lithologic character, from the Cherry Creek series in the type locality, particularly in the abundance of marble members, but also in sequence of rock types. The graphite occurs near the base of this series. At the mines the country rock consists of alternating bands of feldspar-biotite gneiss, biotite schist, and gradations in between. Garnet is present locally in the metamorphic rocks. Marble, dipping about 45°N.W., is present adjacent to graphite at the east end of the district, but this marble member, about 175 feet thick, terminates abruptly near the center of the district just east of the main graphite deposits on the Groundhog Claim.

Many bodies of coarse- to fine-grained granite-pegmatite cut the metamorphic rocks at the mines, and one mass trending northeasterly is 100 feet wide and 800 feet long. Some of the pegmatite contains pyroxene minerals. Most of the pegmatite occurs as small vein-like stringers which stand vertical or nearly so. These pegmatites do not appear to have been deformed by regional metamorphism, and they are probably related to the late Cretaceous or early Tertiary intrusions of Montana.

A dark-colored igneous dike similar to diabase strikes northerly across the graphite-bearing area and stands nearly vertical. Through most of its extent it is about 25 feet thick, but it widens to about 100 feet at its northern end. Other dark-colored dikes are present a short distance west of the

*Peale, A. C., Description of the Three Forks sheet, Montana; U.S. Geol. Survey, Geologic atlas, Three Forks Folio, No. 24, 5pp, 1896.

**Tansley, Wilfred, Schafer, P.A., and Hart, L.H., A geological reconnaissance of the Tobacco Root Mountains, Madison County, Montana: Montana Bureau of Mines and Geology, Memoir No. 9, 1933.



MAP OF CRYSTAL GRAPHITE MINE, BEAVERHEAD COUNTY. (Modified after U. S. G. S.)

main deposits, and a larger dike-like body of similar rock lies north of the mines about one-half of a mile. These dikes have suffered no regional metamorphism, which indicates that they are young in geologic age. Some of the pegmatite has been observed cutting the dark-colored dike rock.

The general strike of the various members in the metamorphic series along Axes Creek and adjacent areas is quite constant N 50° E, and the average dip ranges from 70° to 80° NW. Detailed geologic structure at the mines is obscure largely because of the sudden termination of the massive marble member and the complexity of the gneissic rocks. The marble does not appear to be terminated by major faulting because of the continuity of a marble member about 2,500 feet northward. Near its western termination the marble, which shows good bedding, is extremely crumpled, the small folds one inch to one foot or more in height forming complex patterns; however, there is little or no evidence of brecciation in the marble. It has been suggested that the presence of a large inclined isoclinal syncline with a steep northwest plunge terminates the marble. It has been suggested further that the graphite has been concentrated in a crushed zone along the axis of the fold. Heinrich (oral communication) suggests that the marble is terminated by an igneous intrusion which came into the Cherry Creek sediments prior to their regional metamorphism, and that this igneous rock was converted into gneisses in early pre-Cambrian time by the regional metamorphism which also altered the Cherry Creek sediments. The writer favors the latter interpretation, and he sees no evidence of isoclinal folding of the magnitude necessary to terminate the marble.

Evidence of minor faulting such as slickensided fissures, clay gouges, and breccias, is plentiful in the mine workings. The age of such faulting appears relatively young because of the lack of consolidation and a tendency toward existence of vugs.

Occurrence and Origin of Graphite: The graphite occurs in vein-like bodies and veinlets in gneiss and pegmatite, as disseminations and irregular small masses in pegmatite, and as disseminations in the metamorphic rock essentially gneiss. Most observers use the term vein in describing the deposits because the graphite commonly lies between well-defined rock walls; but the veins are irregular in that they pinch and swell within a few inches developing "bunches" and "pockets" of graphite, and they commonly continue but a few feet, perhaps 10 or 20, both vertically and horizontally. Some may continue much farther. Many such veins are grouped together forming a mineralized zone; and the zone as whole, which may be 100 to 150 feet across, is thought to be persistent from upper to lower levels. The zone or "ore shoot" appears to plunge N 20° W. at an angle of about 45 degrees. Locally a system of veins may be nearly parallel, but in general there is no definite direction of strike. They cut the gneiss and pegmatite indiscriminately, and dips are always steep. Veins may split into two or three strands, and fragments of rock may be surrounded by graphite, in general giving the appearance of a badly crushed zone. Veinlets weave in and out. The deposit as a whole roughly resembles a stock work of graphite-filled fractures with disseminated graphite in the rock between.

In thickness a vein may range from a thin film up to about one foot, and pockets of graphite six feet across have been described. Thicknesses of one to four inches are average. Late minor movements along some of the veins has caused slickensides in the graphite.

The disseminated graphite occurs in or near the vein zones, particularly in the rock between veins. That in the gneiss is generally fine-grained and platy, lies parallel to the gneissic structure, and is interlayered with the minerals of the gneiss. It is more plentiful near veins. Graphite disseminated in the pegmatite is coarser grained, it may be bladed and in radiating clusters and it may occur in irregular masses or in rosettes an inch or two across. Whether this graphite is a replacement, or an original constituent of the pegmatite, or a filling of a shattered rock is obscure in hand specimen.

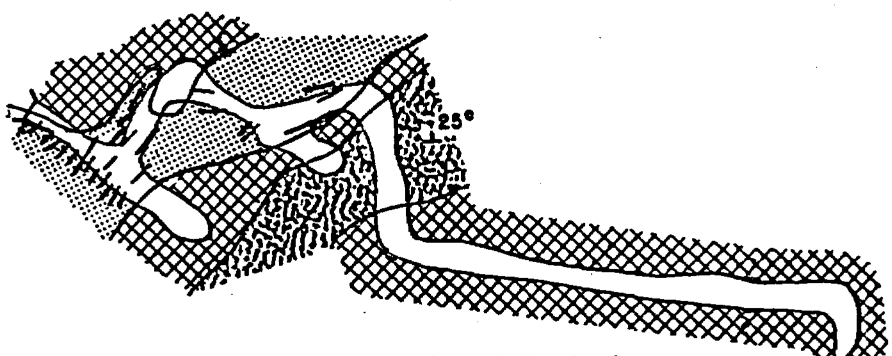
The massive graphite, although clearly crystalline, does not exhibit distinct crystal shapes, but individual crystal flakes which may be one-half of an inch long may be irregularly massed together, or arranged in successive radiating clusters, or in layers of parallel flakes which have grown away from a face of rock into what appears to have been a fissure cavity. In some places comb structure and rudimentary banding have developed by graphite flakes growing in layers parallel to walls of fissures. Radiating clusters of crystal flakes which commonly have the shape of rosettes one-fourth to three-fourths inch across, are conspicuous.

As seen in thin section under petrographic microscope, the disseminated graphite in both the gneiss and the pegmatite occurs as crystal flakes associated with grains of the rock-forming minerals mainly quartz and feldspar: (1) cutting grains in microscopic fractures, (2) "biting" into grains replacing with irregular boundaries, (3) as flakes projecting into grains and terminating within the grain boundaries, (4) possibly as films between grain boundaries. Where the scattered flakes are more plentiful they become massed together forming irregular lumps of graphite in the rock. The boundaries of the lumps show many flakes extending away from the mass. In gneiss the graphite flakes tend to be arranged parallel to the gneissic structure, but many flakes lie in random directions. In pegmatite apparent random orientations predominate, and locally a radial pattern may be developed. The grain size of the graphite ranges from microscopic specks to crystals which may be a half inch or more in length.

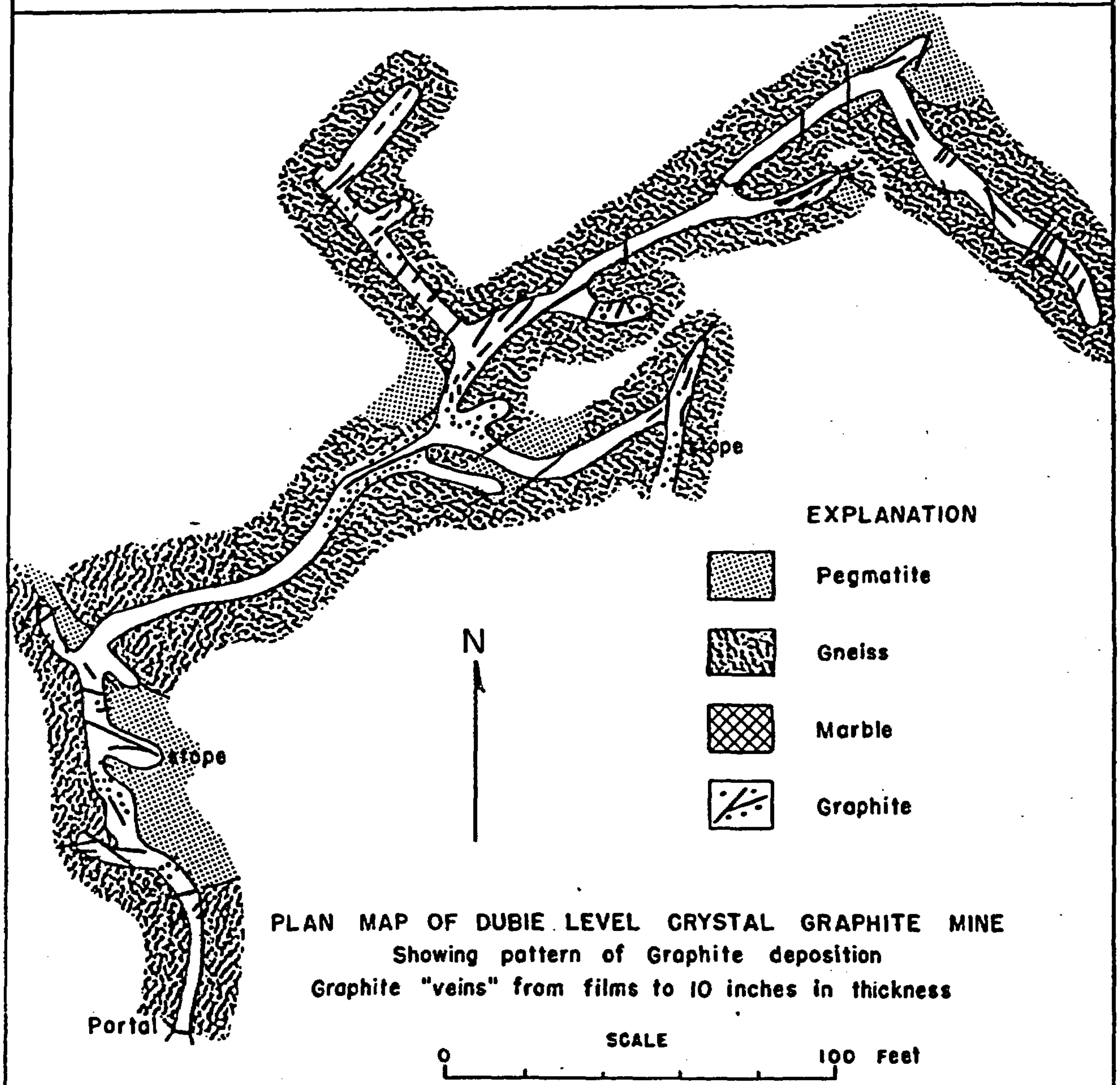
Such conditions of occurrence of the disseminated flakes of graphite indicates a replacement of the rock by the graphite. This, however, does not preclude the probability that much graphite was actually deposited in open cavities and fissures. The presence of the vein-like bodies containing flake graphite arranged in layers parallel to the walls of the vein, and occasionally banded in two or more layers, indicates cavity filling. The flakes in the layers stand at right angles to the walls of the veins. The bulk of the graphite produced so far has come from the vein-like structures.

The origin of graphite is somewhat problematical. It is believed to have formed at depth, before this region was uncovered by erosion, through the action of very hot solutions or vapors given off by deep-seated igneous bodies. It is suggested that these solutions, hotter than the decomposition temperature of calcium carbonate (marble), caused the carbonate to give off carbon monoxide which in escaping and cooling was converted to carbon dioxide, thereby liberating free carbon which precipitated in crystalline form. Intimate association of the deposits with numerous pegmatite dikes and the close proximity of carbonate rocks substantiates this theory. The geologic age of the deposit as inferred from the probable age of the pegmatite dikes, is believed to be very late Cretaceous or early Tertiary. Confirmatory evidence of the late age of the graphite is the occurrence of this mineral elsewhere in the complex in gold-bearing quartz veins conceded to be associated with the Cretaceous-Tertiary intrusives of Montana (Missouri-McKee mine northwest of Ennis).

<u>Mining and Treatment</u>: Practically all mining has been done by underground methods. During the early periods of mining, and until 1943, adits were driven into the mineralized zone, and drifts followed the more important vein structures. In particular, search was made for large pockets of graphite. The massive graphite was dug out from veins and concentrations by means of scrapers consisting of a bent and flattened tip on a long iron rod. It was then gathered



LOWER BIRDS NEST WORKINGS
Showing relationship of marble, pegmatite, gneiss, and graphite.



PLAN MAP OF DUBIE LEVEL CRYSTAL GRAPHITE MINE
Showing pattern of Graphite deposition
Graphite "veins" from films to 10 inches in thickness

on canvas, sacked in the mine, and taken to the surface. As graphite was scraped out, the workings were advanced, and then the cycle was repeated. Disseminated graphite was rejected, and that material removed to facilitate mining operations was taken to the surface and piled into reserve dumps. Such a method resulted in irregular workings and much hand labor. It also resulted in mine dumps containing much graphite.

A total of about 3,500 feet of mine workings has been driven. As may be expected a composite map of all mine workings is most complex. Four main adits from which most of the graphite was mined range in length from 180 to 760 feet, and in altitude from 7,410 to 7,498 feet. Two smaller adits were also driven. Raises and shafts connect upper and lower workings, and some stoping was done. A shaft (now caved) 165 feet deep with workings at three levels has been sunk near the center of the graphite-bearing area. From the Antelope claim, lying immediately south of the Groundhog claim on which most of the mining was carried on, and adit has been driven northward into the mountain about 1,050 feet at an altitude of 7,210 feet which is about 200 feet lower than the main workings. It passed beneath the old workings, but due to what is thought to be a northwest plunge (slope) in the graphite-bearing zone, no graphite was encountered directly beneath the old workings. However, graphite is present at the end of this adit, north of the upper workings, and it would be desirable to extend the adit farther into the mountain.

In 1944 a 125-ton flotation mill was erected to recover fine graphite, and to treat rock containing disseminated graphite. The plant consisted of a simple crushing unit, a simple flotation unit, and a drying unit. Mill feed is reported to have contained 8 to 12 per cent graphite, and concentrates are said to have contained 85 to 90 per cent graphite (carbon). Recovery in the mill was about 85 per cent. The mill has been redesigned, and now includes a jaw-crusher for primary crushing, a ball mill, a flotation unit, a regrinding unit (ball mill), a cleaner flotation unit, a filter, and a dryer. The future plan of operation is to pass the bulk of the graphite-bearing rock through the mill. The mill is about a half mile west of the mine workings on the road to Dillon, and mill feed is trucked from mine to mill. In mining a method similar to shrinkage stoping has been followed since the erection of the mill in 1944, and it is probable that this method will be continued.

An overall average of material mined since 1941 is reported by the operators to have assayed about 12 per cent carbon, and the same average per cent is reported for a group of 32 samples cut in the mine by a party who had no financial interest in the property. Material in the mine dumps and old gobs is said to contain 5 to 8 per cent carbon, and there is probably between 5,000 and 10,000 tons of this type of material available. Sorting out of large pieces of barren rock raises the grade. Reserves of unmined graphite-bearing rock are difficult to calculate because of irregularities in graphite occurrence, and because the graphite-bearing ground has not been entirely delineated. Additional development work is needed to prove the existence of graphite at a depth greater than the main workings. However, there is probably an available reserve of between 100,000 and 200,000 tons of rock of milling grade.

Graphite Mine on the Bird's Nest Claim

The mine on the Bird's Nest claim lie on a heavily timbered mountain slope about 4,200 feet N. 68° E. from the main workings on the Groundhog claim. A bull-dozer road leads part way to the claim. The marble which terminates to the west on the Groundhog claim passes lengthwise through the Bird's Nest claim, and adjacent to the marble are complex gneisses and schists. Granite-pegmatite is present between the two claims, and also in the mine workings on the Bird's Nest claim. The graphite occurs in the gneisses, schists, and pegmatite immediately adjacent to the marble on its south side. No evidence of notable offsetting of the marble by faulting was observed. Three adits have been driven into the mountain slope the longest of which is about 270 feet in length, and some stoping has been done. Practically no timber has been placed in the mine, and the openings are still readily accessible 45 years after mining.

The graphite occurs much in the same manner as on the Groundhog claim, but the veins and pockets appear to have been fewer; and a crushed zone, although present, appears to be smaller and more poorly developed. The pegmatite cuts the schist and the marble irregularly. The graphite veins cut the schist, bend in and out, pinch and swell, and appear and disappear suddenly. Graphite is present in the pegmatite and in close proximity to the marble, but no graphite was actually observed in the marble. The amount of unmined graphite could not be ascertained, but it seems probable that much material of milling grade is present.

Graphite in the Timber Gulch Talc Deposit

An occurrence of graphite of much geological interest is on lower Timber Creek three miles southwest of the Crystal Graphite mines, at the Crescent talc mine of the Tri-State Minerals Company. The mine lies on the lowermost slope of the mountain about one-half mile from the valley bottom of Blacktail Deer Creek. It is accessible by automobile on a dirt road which branches off the road to the Crystal Graphite mines along the east side of the main valley.

Two exposures of marble, 10 to 15 feet thick and separated by about 150 feet of gneiss and schist, have in places been partially or completely altered to talc. The metamorphic rocks, a part of the Cherry Creek series, strike northeasterly and dip northwest at about 50 degrees. The talc deposits have been opened by pits and a shallow inclined shaft to depths of 10 to 20 feet.

Crystalline graphite occurs disseminated through the talc in thin flakes up to one-eighth inch across, the quantity of graphite amounting to perhaps one-half of one per cent. The flakes lie parallel to one another and to the bedding of the marble; and individual flakes are distinctly separate from each other. No commercial significance is attached to this occurrence of graphite at present.

Graphite West of Dell

Occurrences of graphite about 12 miles west of Dell (See fig. 3) in extreme southwestern Montana have been prospected, and although not of apparent commercial value at present, should be briefly described because of interest concerning them. The deposits lie mainly in sections 27 and 34, T. 12 S., R. 11 W., on both sides of the divide between a north fork of Wilson Creek and an east fork of Kate Creek, which in turn are small tributaries of Muddy Creek and Medicine Lodge Creek respectively. No roads which can be traveled by automobile enter the area, and it is necessary to walk one to three miles from the ends of the poor roads which follow the larger creeks. Slopes are steep and divides are 500 feet or more above the creek valleys. Only scattering timber is present.

Numerous pits have been dug, and several adits up to 100 feet in length have been driven on showings of graphite by prospectors and by the National Carbon Company of New York City, the work having been done mainly about 1918. No graphite is known to have been shipped, but it is present in dumps, and can be seen in outcrop and in float.

Most important rock formations exposed in the area are the white crystalline Madison limestone of lower Mississippian age and a complex metamorphic series of gneisses and schists of early pre-Cambrian age. Devonian dolomitic limestone is present north of the main workings.

The metamorphic rocks have been thrown against the Mississippian limestone by a major fault of late Cretaceous or early Tertiary age (Laramide) which extends for miles in a general north to south direction. The displacement is probably greater than 4000 feet. Thick fault gouges as well as breccias are present, and the gneiss appears crushed near the almost vertical fault zone. The fault may be multiple, that is, composed of more than one plane of breaking. The Madison limestone which is uniform in character from place to place shows little evidence of alteration other than recrystallization and the local occurrence of jasper. However, evidence of bedding in the limestone is indeed obscure, and structure in the limestone is difficult to determine.

The metamorphic complex in this locality, although composed of gneisses and schists comparable to the Cherry Creek series in degree of metamorphism, does not contain the same sequence of members, and the members themselves are somewhat different in lithologic types. The rocks are well banded, and the banding stands at steep angles or vertical. Strike of the gneissic banding in the area of graphite deposition is nearly due north, but local irregularities occur. In general, the gneissic series appears more basic (that is, contains more dark-colored minerals) than the Cherry Creek series on Axes Creek, and unusual types of metamorphic rocks are present. One characteristic type of metamorphic rock is composed mainly of hornblende and may be classed as amphibolite. It may be metamorphosed pre-Cambrian dike rock. However, typical feldspar-quartz gneiss with more or less biotite is plentiful and widespread.

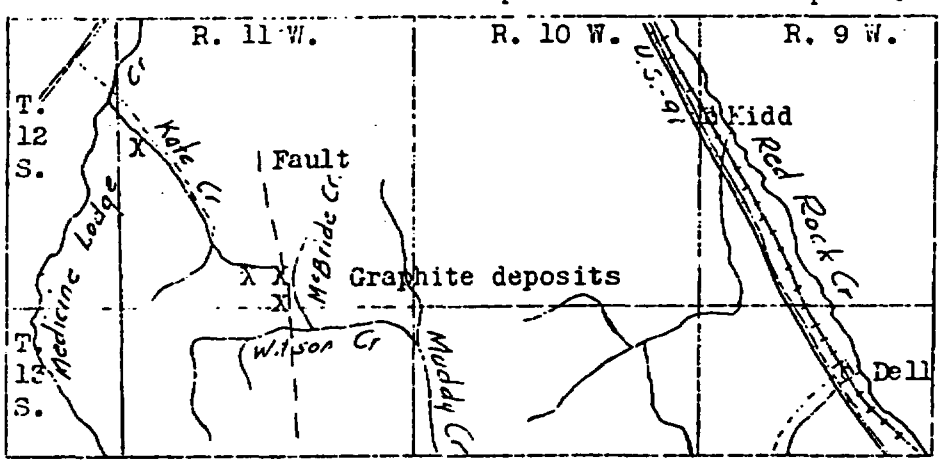


Figure 3.--Map showing location of graphite deposits west of Dell.

No pegmatite dikes of the Cretaceous-Tertiary type, so common in most metamorphic areas in Montana, were observed. Also no marble members in the gneissic series in or near the area of graphite deposition were observed, except that as a coarsely crystalline limestone or a marble which may be of pre-Cambrian age is present near the mouth of Kate Creek about 3 miles northwest of the main deposits.

The graphite is closely associated with the fault zone, and appears to lie in the fault gouge, in fault breccias, and in the crushed gneiss nearby. None was observed in massive solid limestone, but graphite-bearing rock from pits was observed in what appeared to be breccia zones in limestone. The main fault can be traced for perhaps a mile by prospect pits dug along it for graphite.

On the east fork of Kate Creek graphite may be observed in the hillside float and in mine dumps of two adits which lie about one-half mile west of the main fault zone; however, these occurrences may be associated with a complimentary fault in the gneiss west of the main displacement. Another similar deposit of graphite is near the mouth of Kate Creek $3\frac{1}{2}$ miles northwest of those described above. The mode of occurrence and the character of graphite are similar. Two inclined shafts were sunk to a depth of about 30 or 40 feet near a contact between gneiss and coarsely crystalline limestone.

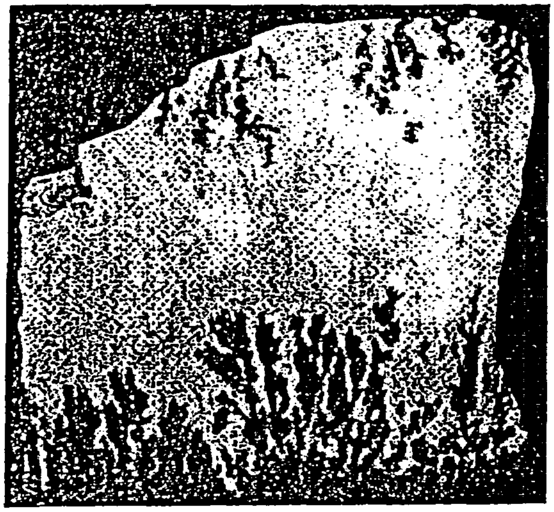
The graphite itself in all of these deposits is fine grained and in hand specimen generally shows as powdery black material, or in flakes too small to be clearly seen with the unaided eye. Under microscope many specimens show crystalline flakes 1/10 to 1 millimeter across, intimately disseminated through fault gouge and breccia, or through gneiss. The flakes lie between grain boundaries of feldspar or quartz, and they may penetrate grains of these minerals. As seen on a saw-cut surface they form an intricate or reticulate pattern of needle-like crystals (probably edges of flakes) growing in all directions but mainly parallel to the gneissic structure. In fault gouge, flakes of graphite are in the fine clay and in the rock fragments alike, and flakes extend from within the fragments to beyond their limits. Some hand samples may contain 50 per cent or more of graphite. A composite analysis of material taken at random from four different mine dumps on the Kate Creek side of the divide shows approximately 12 per cent carbon.

The graphite-bearing zone appears to stand nearly vertical, and as observed on hill slopes is continuous in the vertical dimension at least 200 feet. The graphite evidently has replaced the pre-existing minerals of the gouge, the breccias, and the gneiss; and it has been introduced into its present position, probably by hot solutions or vapors rising along the ruptures created by the large fault.

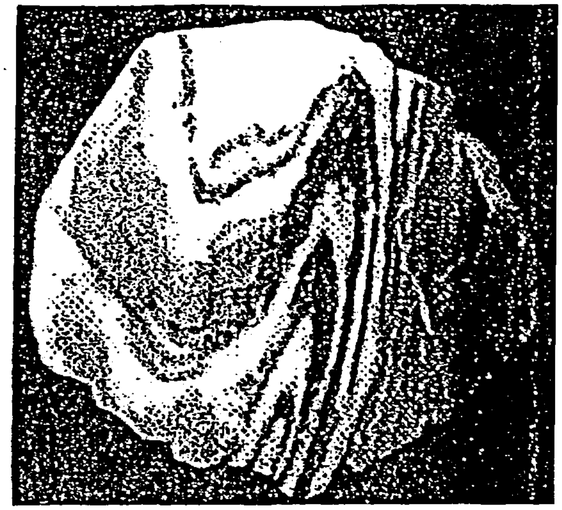
The commercial possibilities of the deposits would seem to depend on the development of a suitable method of milling whereby the rock-forming minerals could be separated, because the material as it comes from the mine is not of commercial grade. Since only graphite and the common rock forming minerals are present, flotation should yield a satisfactory concentrate. Grinding would have to be fine to liberate the particles, but the rocks are soft and should grind easily. Mine workings are not such that reserves can be calculated. Although graphite was observed for nearly a mile along the fault zone, no doubt it is more concentrated in some places than in others. The first procedure in any attempt to exploit the deposit would be to determine the amount of milling material available, and the per cent of carbon it contains.

Scattered Occurrences of Graphite

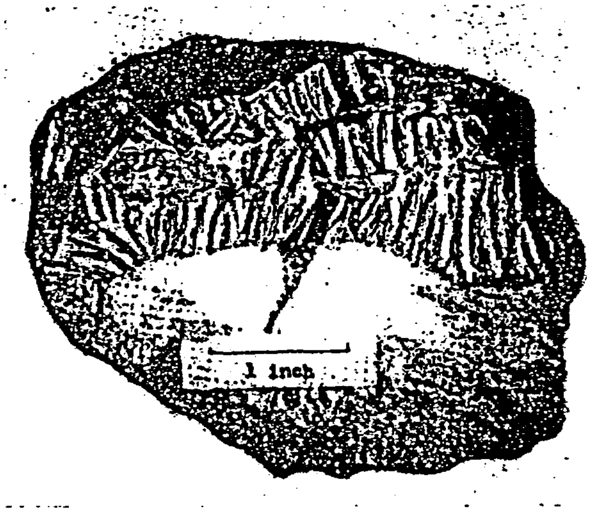
Crystalline graphite is known to occur in minute flakes and small amounts in many localities in southwestern Montana, particularly in the metamorphic rocks. Generally it is not recognized due to the small size of the flakes. Commonly where talc is found microscopic flakes of graphite have been observed either in the talc or in the adjacent rocks. Graphite accompanied a gold-bearing quartz vein at the Missouri-McKee mine west of Ennis. Hand specimens, generally gneiss, containing a minor amount of graphite in microscopic flakes are sent to the Montana School of Mines for identification. The mode of occurrence appears to be similar to that previously described, and these occurrences suggest that the graphite-producing process occurred over a wide region. However, since all of the mountains of Montana have been carefully prospected again and again for metals, it is unlikely that large commercial bodies of



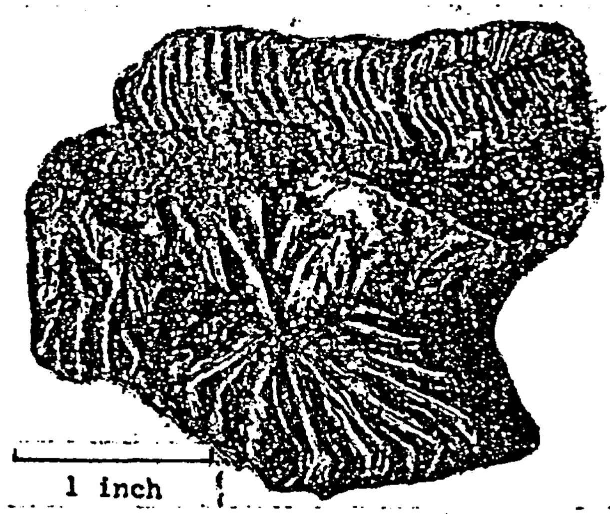
A. DENDRITIC TALC—JOHNNY GULCH



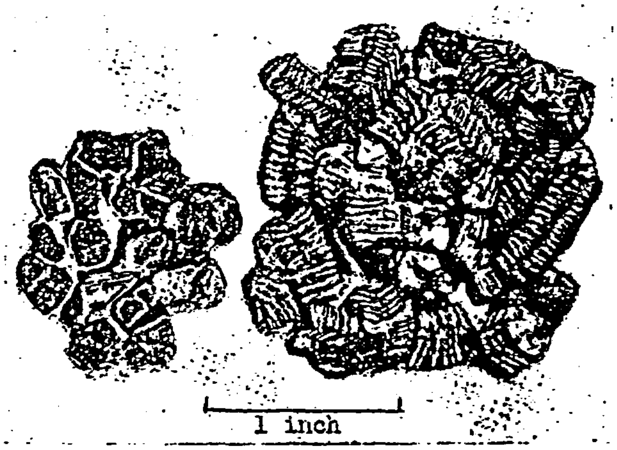
B. BANDED TALC—JOHNNY GULCH



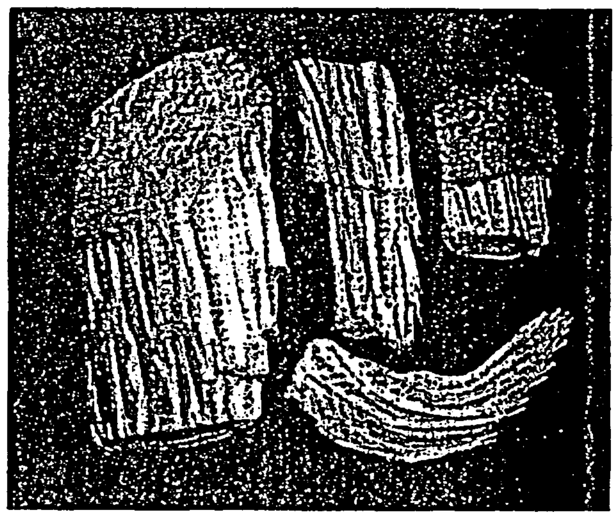
C. GRAPHITE VEIN WITH PEGMATITE
Crystal Graphite Mine



D. GRAPHITE ROSETTE
Crystal Graphite Mine



E. VERMICULITE—LIBBY
Left, unexpanded—Right, expanded



F. ASBESTOS—KARST

PHOTOGRAPHS OF SPECIMENS OF NON-METALLIC MINERALS crystalline graphite have been overlooked. If found they would be expected to be in areas of gneiss with marble or limestone nearby, and the presence of pegmatite would be an additional favorable indicator.

Beds of carbonaceous and petroliferous shale up to 100 feet in thickness are present in the Paleozoic and Mesozoic series of sedimentary rocks in Montana, but the carbon in them is not in the form of graphite. Some of the petroliferous shales (commonly called oil shale) will hold a flame when heated with a match, and will yield 10 to 20 gallons of oil per ton of shale by destructive distillation. When such material is crushed in large fault zones, many of which are present in western Montana, it takes on a greasy shiny black appearance, and being soft somewhat resembles graphite. A deposit of this character is reported to be present north of Melrose near Big Hole River. Little or no commercial significance is attached to such occurrences so far as graphite is concerned since the carbon could not readily be concentrated from the shale minerals which constitutes the main mass of rock. This material might have some value as a mineral body in paint or other commodities.

Although coal is present in the younger strata in the mountains of western Montana, it is not definitely known to have been converted into graphite. Furthermore, the various Montana occurrences of crystalline graphite are not believed to have had any genetic relationship to deposits of coal or carbonaceous material, excepting as limestone and marble contain carbon.

PART III. VERMICULITE

General Considerations.

The vermiculite deposit near Libby, Montana, recognized as such in 1918, is the first to be worked in the United States successfully on a large commercial scale; and development of this deposit, beginning in 1923, marked the initiation of a new industry not only in this state but in the nation. In 1947 this industry yielded over a million dollars from material mined. Although the Libby deposit is the only one being operated in Montana at present, other deposits of this unusual mineral are known in the state, and their future awaits systematic exploration and development.

Vermiculite is an unusual mica-like material which receives its name from its peculiar property of expanding and opening out into worm-like forms when heated to red heat. (Latin--vermiculari, to breed worms). Good vermiculite should expand 12 to 15 times its original volume. The mineral occurs as flat tabular greenish to brownish crystals which can be separated into thin sheets, and it differs from true mica in that the sheets when bent will not spring back to their original shape. Its hardness is about 1.5 and its specific gravity 2.3 to 2.4. The simplest test for vermiculite is to heat it and observe its expansion--other types of micaceous minerals will not expand. In composition vermiculite is a hydrated silicate of magnesium, aluminum, and iron in which the chemically combined water amounts to about 20 per cent. Percentage of constituents may vary comsiderably.

The principal use of vermiculite is in heat, cold, and sound insulation. It may be fabricated into blocks, bricks, or wall board with the aid of a binder; it may be used in plaster; and it is used for many other purposes such as for packing, lubricants, rubber goods, and in paper, inks, and paints. Its acoustic properties are notable. A very large quantity is used in loose form for heat and fire insulation in walls and ceilings.. It also is used as a light-weight aggregate in concrete, and plaster, and this is now the largest use of this material. It has some practical value in its natural state, but most of the vermiculite is expanded prior to use. The expanded material will float on water. Tyler* in 1938 stated that "For expanded vermiculite the standard volume ratio is 6 pounds per cubic foot, but varieties that cannot meet this standard are likely to be used increasingly, although perhaps not at the same price per ton or even per bag."

As an insulator vermiculite competes with mineral or rock wool, a manufactured product made by forming fine fibers from molten rock blown into a stream of air or steam, and there are other competing materials.

Vermiculite has been found and worked in several other states and in foreign countries. Deposits were discovered in North Carolina as early as 1873 and in Pennsylvania about the same time. Several deposits were discovered in Colorado about 1913, and in Wyoming in about 1938, and this natural resource occurs in other states. Considerable vermiculite has been mined and shipped from Colorado and Wyoming. Vermiculite is being mined and expanded in South Carolina on a large scale, and these deposits are the source of supply for southeastern United States. Large deposits of vermiculite occur in Africa; some has been shipped to the United States, and foreign producers are encroaching on the American market. As this inconspicuous and seldom recognized mineral becomes better known, it is probable that additional deposits will be discovered.

Actually the term vermiculite includes a group of similar minerals which are essentially alteration products of biotite or phlogopite (black and brown

*Tyler, P. M., Minor nonmetals: U. S. Bur. Mines, Minerals Yearbook, 1938, p. 1314.

micas) or possibly hornblende, which are present as the ordinary constituents of dark-colored intrusive igneous rocks such as peridotite. However, vermiculite is also observed in layered or metamorphic rocks such as mica schists or gneisses. The cause of the alteration is uncertain; it is generally assigned to hydrothermal (hot water) action, and bearing on this mode of origin is the regular association of pegmatite dikes with vermiculite deposits. An alternative theory for its origin is by action of weathering and surface waters; but it seems probable to the writer that, even if weathering has had a part in the alteration, it is subsequent to an earlier deep-seated change in the original minerals. These considerations have a bearing on continuation of deposits with depth, in that if the material has been developed by weathering, deposits would be expected to be relatively shallow, but if developed by hydrothermal solutions, deposits would be expected to continue to considerable depth.

In Montana this mineral is known to occur in several localities, chief of which are near Libby, Lincoln County; Hamilton, Ravalli County; Pony, Madison County; and in the Bearpaw Mountains near Box Elder in Hill County. Other deposits of micaceous minerals similar to vermiculite also are known, for example on Squaw Creek south of Bozeman. All of these occurrences, except near Pony and vicinity, are of direct igneous origin, the mineral being found in large intrusive masses or dikes. The deposits near Pony and in the region southward occur in pre-Cambrian biotite or hornblende schists. Pegmatite dikes cut the vermiculite deposits in most cases, and they are always in the immediate vicinity of the vermiculite. The vermiculite in the large intrusive masses appears to occur as local concentrations where dark (ferro-magnesian) minerals were originally more plentiful, or else where zones of alteration were more intense; however, certain dike-like bodies are almost all vermiculite. High grade vermiculite bodies are generally very irregular and more lens-like in character at Libby, and dike-like bodies are rarely seen. Because of its mode of origin, vermiculite is to be expected only in the mountainous areas in Montana, as it is only in these areas that conditions suitable for its formation existed.

Vermiculite deposits near Libby

The deposits of vermiculite near Libby are the largest yet worked, and a reserve for many years has been proved. They lie seven miles northeast of Libby, and are readily accessible by automobile by traveling first for four miles east along State Highway No. 37 which follows the north side of Kootenai River, and thence three miles northeast up Rainy Creek. The elevation of Libby is 2050, and of the vermiculite mines between 2,800 and 4,200 feet. Topography may be considered mountainous, and slopes which rise abruptly 1,000 to 2,000 feet above the major drainage are for the most part heavily timbered.

Libby, whose population is about 3000 is on the main line of the Great Northern Railway, and also on U. S. Highway No. 2. Large lumber mills are at Libby, but grazing and some agriculture and metal mining are carried on in the surrounding region. Annual precipitation may reach 50 inches, and snow is deep in winter.

The deposits, discovered about 1915, were soon investigated by Mr. E. N. Alley who, seeing the commercial possibilities of the expanded material, experimented with the processing and utilization of the vermiculite, and he devoted time to promoting its development, a difficult task because the material was so little known. However, the Zonolite Company was eventually formed, and commercial production on a small scale began in 1925 from material taken from shallow open-cut workings. The vermiculite was expanded in a small expansion plant whic had been erected at Libby in about 1922.

Two other companies, the Micalite Company and the Vermiculite and Asbestos Company, were subsequently formed in 1926. The former did not function long, but the latter sunk pits and drove adits on exposures of vermiculite lying northwest of the original discovery. In 1931 the Dominion Stucco Company of Manitoba acquired an interest in the Zonolite Company. In 1934 the first concentrating plant was erected near the mines. In 1939 the Zonolite Company and the Vermiculite and Asbestos Company merged to form the Universal Zonolite Insulation Company, leaving but one company operating in the district. In 1948 this company changed its name to Zonolite Company, head office of which is in Chicago, and the Zonolite Company now operates the mine, the mill, and the marketing of the product. The original concentrating plant has been remodeled and enlarged from time to time between 1936 and 1947, and the process of concentration changed as more improved methods were developed. The present mill (1948) uses approximately 1,000 tons of feed per day which yields between 350 and 400 tons of concentrate. The original expansion plant at Libby has been reconstructed.

Production of crude and expanded vermiculite gradually increased as the product became better known from meager shipments in 1925 to about 20,000 tons in 1940, and 75,000 tons in 1946. The value at the beginning of operations of the unexpanded vermiculite at the mines was approximately $12 per ton, but with increasing volume of production, varying market conditions, and demand for various grades, prices have ranged from $8 to $13.50 per ton at the mines. The value of expanded vermiculite (f.o.b. processing point) ranges from $.70 to $1.25 per bag of four cubic feet weighing about 25 pounds, which is a rate of from $56 to $100 per short ton.

Mining at Libby has been carried on mainly by means of open cut methods, the rock being dug with power shovels and hauled by half-track truck and conveyor belt to the concentrating plant which is near the mines. Selective mining is practiced. Dimensions of the pit are: length 1200 feet, width 700 feet, maximum depth 100 feet. The concentrate is hauled by truck to Libby where it may be expanded, or as is the case with most of the material, shipped unexpanded to a plant at Great Falls and to cities in other states, Canada, and foreign countries. Several adits have been driven, and one adit 750 feet long has been driven beneath the open cut so that it crosses the deposit at a depth of 265 feet beneath the surface. The general character of the vermiculite in this adit is not particularly different from that near the surface.

The separation of mixed rock minerals and vermiculite has proved difficult, and several methods have been tried. Wet processes yielded satisfactory separation, but was considered less economical than other methods. Flotation is not suitable for concentrating coarse material. Various applications of air suction, of air lift, and of electrostatic separation were tried. At present concentration is accomplished essentially by sizing and screening in conjunction with differential crushing, and a recovery of between 75 and 80 per cent is achieved on run-of-mine material averaging from 40 to 50 per cent vermiculite. A concentrate containing 90 per cent vermiculite is obtained. Extensive studies on concentration, processing, and utilization are being continued.

Weight of the unexpanded Libby vermiculite concentrate is about 55 pounds per cubic foot, and the weight of the expanded material is about 6 pounds per cubic foot. During the process of expansion a loss in weight of about 10 per cent occurs, due mainly to escape of chemically combined water, although not all of the combined water is driven off. The expansion of the crude mineral is achieved by heating quickly to a red heat (1600° to 2000° F in 5 to 10 seconds). The material is then cooled rapidly, the rapid cooling resulting in better pliability and toughness to the rather brittle particles. Several types of exfoliators are in use. One difficulty encountered in exfoliation is that the partly expanded particles tend to insulate themselves and thus prevent complete exfoliation. When vermiculite is expanded in an oxidizing atmosphere, it yields a golden-colored product. In a reducing atmosphere, the end product is silver-colored. This characteristic is important when expanded vermiculite is used in paints, pigments, and inks.

Geology

The general geology of the area was first studied in detail by Pardee and Larsen*, although other investigators and the writer also have studied the area. This part of Montana is underlain by quartzite and argillite (hardened sandstone and shale) and impure limestone of the Belt series of uppermost pre-Cambrian age,

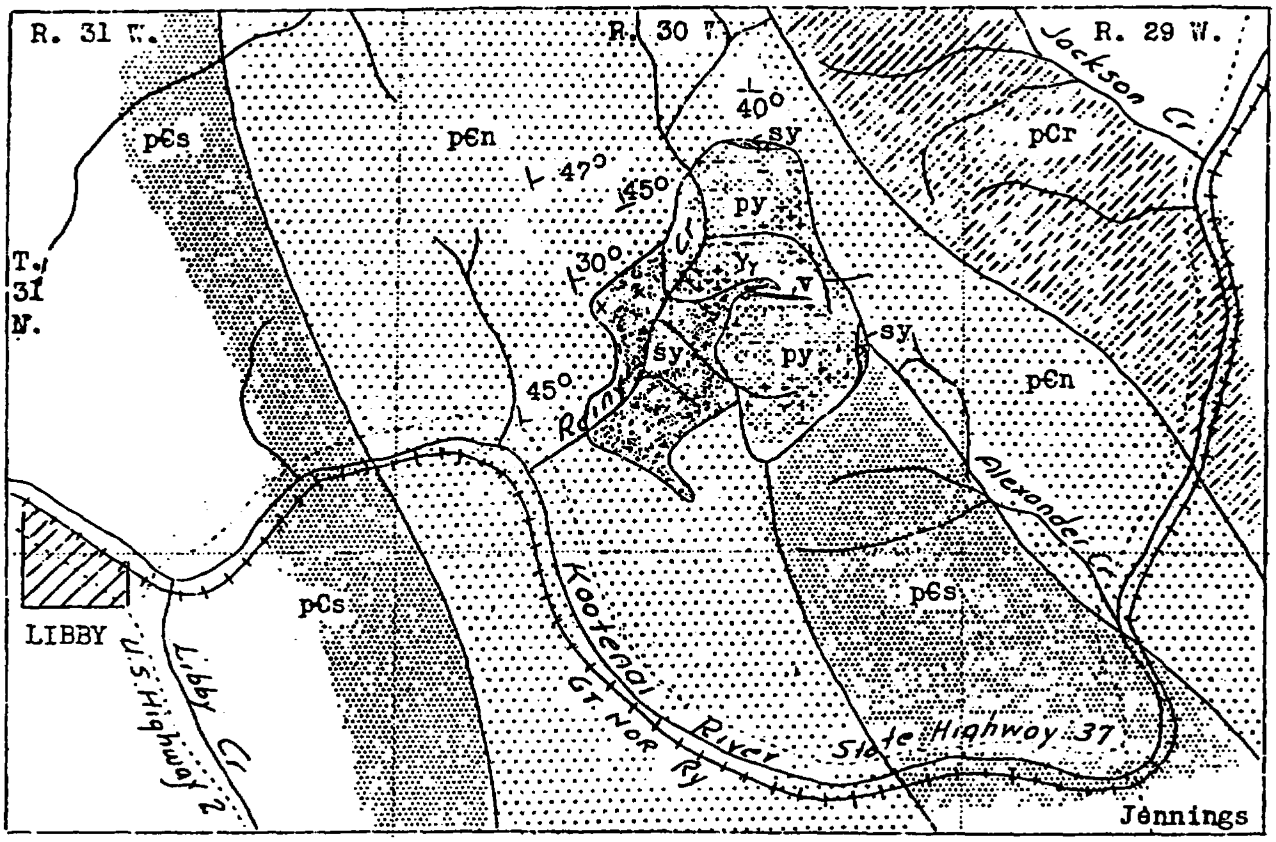


Figure 4.--Geologic map of Libby vermiculite deposit, Lincoln County. p€s, Spokane formation; p€n, Newland formation; p€r, Ravalli formation, sy, syenite; py, pyroxenite; v, biotite rock altered to vermiculite.

totaling more than two miles in thickness. The general regional structure at Rainy Creek is a large open syncline in which the Spokane and Newland formations (subdivisions of the Belt) lie in the center. Minor folding and faulting are present, and dip of strata is commonly 30 to 50 degrees. At Rainy Creek intrusions of pyroxenite and syenite, together with some pegmatite, intruded the Belt strata in late Cretaceous or possibly early Tertiary time, and these rocks

*Pardee, J. T., and Larsen, E. S., Deposits of vermiculite and other minerals in the Rainy Creek district near Libby, Montana: U. S. Geol. Survey, Bull. 805-B, pp. 17-29, 1929.

now form a stock about four miles long and two miles wide. Proportions of the pyroxenite and syenite are about two-thirds and one-third respectively. (See map, figure 4). The vermiculite is a constituent of the pyroxenite.

The pyroxenite, first intrusive of this group, is a coarse-grained dark-colored rock with a greenish tinge, so altered that it can be crushed by squeezing in the hands. In the shallow workings holes for blasting could be drilled with an auger if so desired, however excavation is essentially by power shovels without blasting. Mineral composition of this intrusive differs from place to place from nearly pure pyroxene (diopside) to nearly pure biotite. Alteration has produced vermiculite and in some places amphibole asbestos. Apatite (calcium phosphate) containing much fluorine may constitute 5 to 10 per cent of the rock, an amount unusually high, and titanite and magnetite with ilmenite are locally present up to 10 per cent. Feldspar is present in varying amounts, generally less than 15 per cent. Vanadium is a minor constituent of some of the pyroxenite, although it is reported to be present up to four per cent in small concentrations.** The vermiculite-bearing area has been described as lying in a zone about 2000 feet wide and two miles long striking northerly. Hard, resistant vertical syenite dikes 5 to 10 feet wide lie parallel and form "ribs" in the vermiculite zone.

Specific gravity of the pyroxenite is about 3.4. An analysis of a sample of the pyroxenite shows the following constituents calculated in terms of oxides of metals, although of course practically all constituents are in the form of silicate minerals.

Analysis of pyroxenite from Rainy Creek, Montana*

	per cent		per cent
Silica	37.47	Sodium and potassium oxides. .	1.30
Alumina.	2.86	Water.	1.00
Ferric oxide . . .	11.77	Titanium oxide	1.07
Ferrous oxide. . .	7.83	Phosphorus pentoxide	4.33
Magnesium oxide. .	10.12	Vanadium oxide	0.12
Calcium oxide. . .	21.68	Fluorine	0.36

The syenite is medium to coarse grained, nearly white when fresh, but iron-stained on weathered surfaces. In addition to the main mass are the many dikes which cut the pyroxenite, and it is suggested that the large body of syenite may actually be made up of several smaller separate intrusions massed together. Mineral composition is chiefly potash and soda feldspars with about 15 per cent muscovite locally, and accessary minerals are dark diopside and hornblende, fluorite, apatite, titanite, biotite, and garnet. The syenite differs both in texture and composition with locality, and at the south end of the stock a syenite dike containing nepheline and albite is reported.

Pegmatite dikes are rather common. Three different types have been noted: (1) mafic, that is, dark colored and composed largely of pyroxene; (2) syenitic, that is, light colored and composed mainly of feldspar without quartz; and (3) granitic, that is, composed mainly of feldspar with quartz. This order is also probably the age sequence. The granitic types are small and most common, they cut all rocks of the district, and they grade into glassy quartz veins which locally contain small amounts of copper, lead, and manganese minerals. The syenitic pegmatites grade along their strike into ordinary syenite, and they

**Larsen, E. S. and Hunt, W. F., Two vanadiferous aegirites from Libby, Montana: Am. Jour. Sci., 4th ser., vol. 36, no. 213, pp. 289-296, 1913.
*Pardee, J. T. and Larson, op. cit., p. 21.

appear to be associated with a wide-spread wave of hydrothermal alteration w affected the pyroxenite, altering pre-existing minerals to vermiculite, asbe tos, and sericite mica.

The vermiculite has no natural exposures, but soils in the outcrop area show mica-like flakes, and have a yielding, slippery feel under foot. Vermiculite occurs disseminated in the pyroxenite throughout its area of exposure and in several dike-like or irregular lens-shaped concentrations the rock ma be nearly pure vermiculite. Locally, crystals (books) up to ten inches acro may be irregularly massed together, but in the pyroxenite, crystals are commonly less than one or two inches across. The margins of concentrations generally grade into the pyroxenite, the amount of pyroxene increasing until th amount of vermiculite may be less than 10 or even 5 per cent. The concentraions have a nearly vertical trend, and may be as much as 100 feet wide and 1000 feet long, although their width is more commonly 20 to 40 feet. Slip planes cutting the concentrations of vermiculite are common, but are apparen ly much later and had quality of the vermiculite.

The chemical composition of the vermiculite, as analyzed by the Nationa Bureau of Standards, is as follows:

Analysis of vermiculite from Rainy Creek, Montana

	Per cent		Per cen
Silica	41.0	Magnesium oxide	21.0
Alumina	18.0	Sodium and potassium oxides	1.0
Iron oxide	7.0	Moisture	11.0
Calcium oxide. . .	1.0		

Information on reserves of vermiculite is not available, but it is reported be adequate for many years to come. The grade over a period of years has me all market requirements, and there is no indication that grade will change within the known bodies of reserve material.

Vermiculite deposits near Hamilton.

The vermiculite deposits on Gird Creek about 11 air-line miles east of Hamilton (see figure 5) have been opened only by shallow pits and short adi Extensive tests on the grade of material (amount of expansion, etc.) have no been made throughout all parts of the area. The deposit of vermiculite-bearing rock, about three miles long and one mile wide, shows promise of being commercial, and would seem to warrant additional development work.

The deposit may be reached from Hamilton by automobile over about 6 mil of graded road and 12 miles of mountain road the last half of which has been cut by bull-dozer along a steep mountain slope on the north side of Gird Cre drainage. The area is near the crest of the south end of the Sapphire Mountains, a rugged range thickly covered with timber and reaching altitudes of over 8000 feet or about 5000 feet above Bitter Root River valley at Hamilton State Highway 57, locally known as the Skalkaho road, crosses the range abou 2½ miles southeast of the deposit; but only trails extend from the deposit t this highway. Creeks flowing east and west from the Sapphire Range pass through deep narrow canyon-like valleys mostly inaccessable by automobile. Much of the immediate area of vermiculite-bearing rock has been the site of forest fire, and fallen timber causes difficulty in traveling.

Hamilton, population about 2000, is the county seat of Ravalli County. It is on a branch line of the Northern Pacific Railway 48 miles south of

Missoula, and also on U. S. Highway 93, an oil-surfaced road which extends from Missoula to Salmon, Idaho.

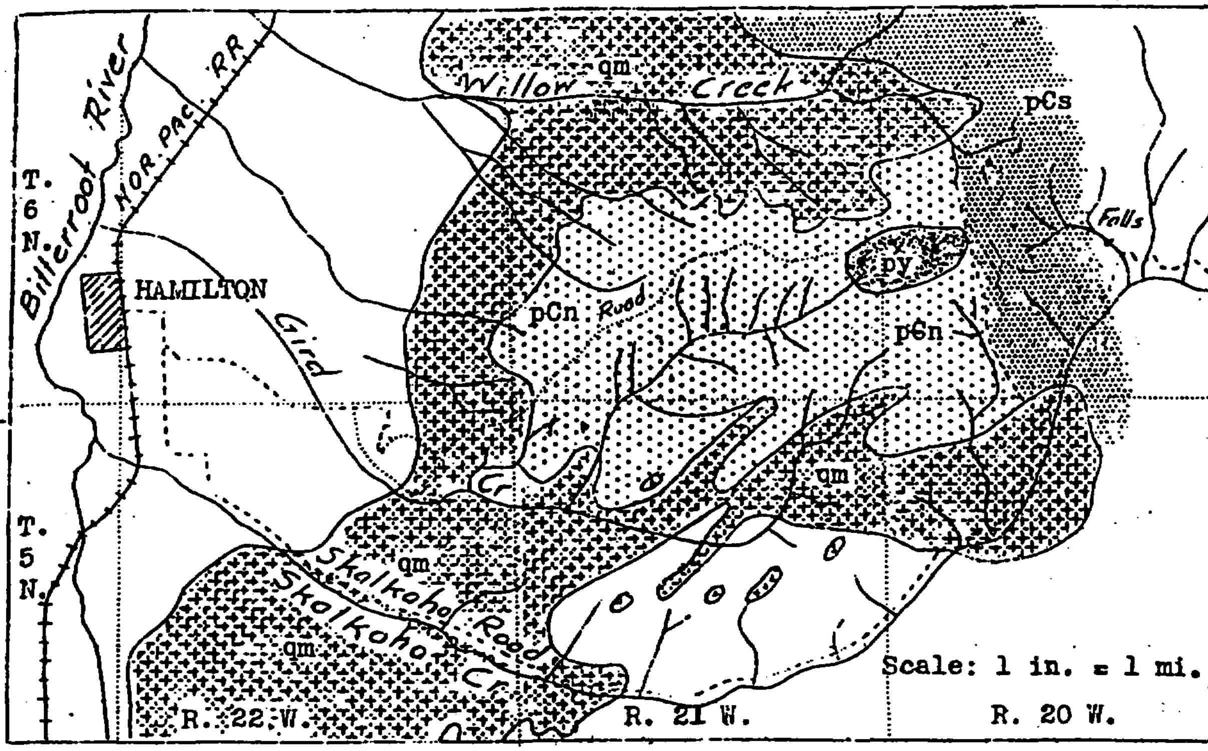


Figure 5.--Map showing location of vermiculite deposits near Hamilton. pЄs, Spokane formation; pЄn, Newland formation; qm, quartz monzonite; py, vermiculite-bearing pyroxenite,

Mining claims were first laid out on the deposits in 1930 by Mr. S. H. (Swift) Chamberlain of Victor (now deceased) and associates. Prospecting by means of pits took place in the next two or three years. Numerous interested parties, including the Universal Zonolite Insulation Company, have examined the property. During the summer of 1948 the F & S Construction Company of Butte investigated two localities, one near the west end of the area and one on Horse Ridge, by means of bull-dozer cuts, and had samples tested for expansion and purity. Although the vermiculite was considered to be of commercial grade, development work was not continued because tonnage available was in question.

The vermiculite occurs in an intrusion of pyroxenite (dark-colored igneous rock) which cuts impure limestone and argillites of the Newland formation of the Belt series of pre-Cambrian age. Associated with the pyroxenite are intrusive masses of syenite and also pegmatite dikes. Extensive areas of granitic intrusions (quartz monzonite) are also present in this general region, and they probably mark the eastern margin of the Idaho batholith. In general, the area underlain by pyroxenite is soil covered, but exposures of underlying rock may be observed plentiful enough to permit detailed mapping.

Petrographic studies of the rock types and mineral alterations show that the Hamilton deposit is very similar to the Libby deposit in all of its general characteristics, although the two deposits are 175 miles apart. Additional rock types are hornblendite and meladiorite, both of which resemble pyroxenite in hand specimen. Both magnetite and titanite (sphene) are plentiful, the former ranging up to 15 per cent and the latter up to 4 per cent.

Apatite is plentiful also, and unusual silicate minerals such as tourmaline and titaniferous garnet may be observed.

The vermiculite (or hydrobiotite at some places) occurs as disseminations and as concentrations in the pyroxenite. Some occurs in dike-like or tabular bodies six inches to two or three feet in width in which crystals one to four inches in diameter are present. Many of these stringer-like concentrations cut the pyroxenite nearly vertically. Such a condition was observed near the west end of the area, but it is probable that similar conditions occur elsewhere. Some basic pegmatite is present. Much of the vermiculite is fine grained (1/32 to 1/8 inch), and occurs in a more or less solid mass sparsely mixed with other minerals. Such is the case on Horse Ridge, a narrow ridge extending south-westward at about the middle of the area. Only trenches and pits have been dug at this location, but there appears to be a sizeable concentration which grades into the pyroxenite on its margins. About one mile east of Horse Ridge additional occurrences may be observed. A 50-foot adit has been driven into a mass of the mica-like material, and vermiculite is present throughout its length. Several pits have been dug nearby, and vermiculite is exposed in road cuts along the switch-backs which take the road to the divide of drainage. On this divide at 8000 feet altitude are more pits in vermiculite-bearing rock.

The accompanying map (fig. 5) shows the area of dark-colored igneous rock as outlined by the prospectors who staked out the mining claims. It is their word that vermiculite may be found from place to place throughout the area. The writer has observed it across an area about three miles long.

Preliminary tests show that the vermiculite from different places exhibits somewhat different ability for expansion, however material of commercial grade is present. Material from the central part of the area (Horse Ridge) which weighed 86.6 pounds per cubic foot unexpanded yielded an expanded material weighing 11.2 pounds per cubic foot. This material contained about 18 per cent of material which did not respond to expansion processes. Another sample, small in size, had a weight of between 60 to 70 pounds per cubic foot before expansion, and about 15 pounds per cubic foot after expansion.

Before operation, thorough sampling and testing for quality should be made from place to place throughout the area, and tonnages of minable material should be determined. It is probable that success of any large-scale operation will require milling of the run-of-mine material to remove rock or associated minerals which would be included with the vermiculite in the process of mining.

Vermiculite deposits in the Bearpaw Mountains near Boxelder.

Material classified as vermiculite has been discovered and opened by pits, adits, and inclined shafts in the Bearpaw Mountains 25 miles east of Boxelder on the Rocky Boy Indian Reservation. (See figure 6) Boxelder, a town of about 300 population, is on a branch line of the Great Northern Railway 23 miles southwest of Havre which is county seat of Hill County in which the deposits lie. State highway No. 29 passes through Boxelder. Good graded roads extend from Boxelder to within 15 miles of the deposit, and easily traveled mountain roads continue to the deposit. The altitude of Boxelder is 2,682 feet, and of the deposits, which lie near the head of the north fork of Big Sandy Creek, is about 4,000 feet.

Havre, the principal city in this part of Montana, has a population of about 7,000. Principal industries in this region are stock raising and grain farming. No extensive minging has been carried on, although coal is present in this part of Montana. Natural gas occurs near Havre.

The Bearpaw Mountains, essentially a pile of lava and associated intrusives on and in relatively flat-lying upper Cretaceous strata, stand out island-like at the western margin of the Great Plains which stretch out as a level floor for many miles in all directions. Rapidly eroding streams have cut deep valleys into the plains.

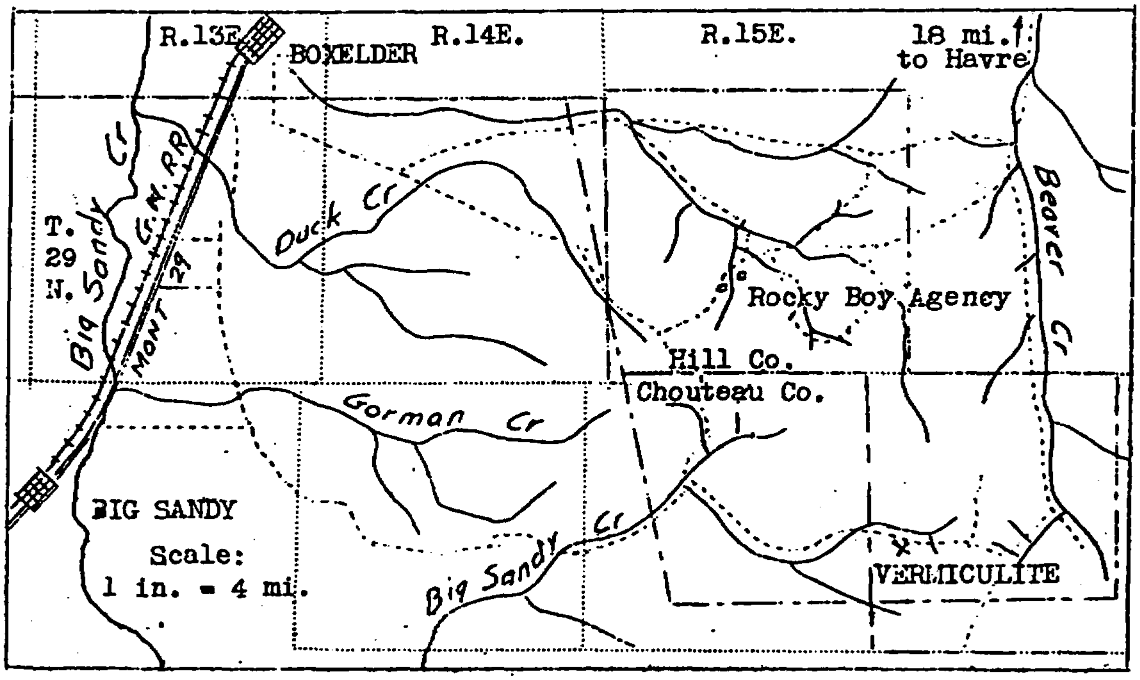


Figure 6.--Map showing location of vermiculite deposit in the Bearpaw Mountains, Hill County.

The Bearpaw Mountains are unique to geologist in that the igneous material which broke through the flat-lying blanket of young sediments contains unusual minerals and unusual types of rocks (potash rich). In places the strata have been bent into folds and domes, and laccolithic structure occurs. Although this area was a seat of volcanoes, the time is so remote that erosion has removed topographic evidence of their existence, and now in the heart of the mountains only the "roots" of these eruptions are present.

The deposits were first opened in 1929 when an air compressor and other machinery for mining operations were installed and cabins were built. Effort to market the material met with little success, and after a few years operations ceased and machinery was removed. Since the recent war interest has been revived, and during the summer of 1947 mine workings were being cleaned out, and put into condition for operation.

The vermiculite may be observed in an open cut about 40 feet above creek level, and in an adit driven beneath the cut. Several dike-like concentrations which stand nearly vertical are from two or three inches up to nearly four feet in width. These have been described as basic pegmatite dikes. Altered rock, now essentially clay, separates the micaceous material; but at the sides of the cut relatively fresh rock (syenite and momzonite) is present. The main mass of rock comprising the intrusive in which the vermiculite deposits lie is monzonite, a rock somewhat similar to granite but containing no free quartz. The deposit present in the open cuty may be traced up the steep slope by means of pits for perhaps 200 to 300 feet. Another body of the mica-like material has been opened 225 feet west of the cut by means of an inclined shaft. Still other occurrences are opened by pits or adits 300 feet across the valley, but the amount of vermiculite at this location appears negligible. The material is in the form of thin dikes cutting syenite.

Material from different places exhibits a difference in its ability to expand. That from the open cut and underlying adit appears best. That from the inclined shaft resembles biotite mica more closely. It has been suggested by operators that vermiculite of better grade is near the land surface, whereas that material farther underground has not been altered as much, and consequently does not expand as much when heated. This observation was not verified. In general the material does not meet the specifications given by Tyler (See page 23). Showings in the present mine workings indicate that the deposit is limited in size, but it would seem probable that with selective mining much material can be produced.

Vermiculite deposits near Pony.

The vermiculite deposits about 4 miles northwest of Pony (See figure 7) and other deposits reported in Madison County (county seat, Virginia City), are quite different from those just described in that they are alterations of a biotite or hornblende schist which is a unit within the pre-Cambrian metamorphic complex widespread in southwestern Montana. No commercial production has been attempted from these deposits, but prospect pits have been dug, and northwest of Pony several extensive cuts have been made by means of a bull-dozer, uncovering the material to a depth of 5 to 10 feet over areas 20 to 50 feet wide and 25 to 100 feet long. Development was carried on about 1940.

Pony, population about 300, is on a branch line of the Northern Pacific Railway. A good graded road extends to Pony from State Highway No. 1 at Harrison, a small town six miles distant from Pony. Dirt roads, which are rough but passable, extend north from Pony and west from Harrison, converging toward South Boulder Creek. The bull-dozed area lies about one and one-half miles north of the road to South Boulder Creek, and three miles east of this creek. A field road easily traveled by automobile leads northward to the deposit. No prominent exposures of the vermiculite-bearing rock may be seen, although examination of the soil reveals particles of the mica-like material, The deposits lie near the divide of drainage on a gently west-sloping surface on which vegetation consists mainly of grasses and sage brush, and scattered pine trees. This region is in the northern foot hills of the Tobacco Root Mountains. The altitude of Pony is 5443 feet above sea level, and of the deposits about 6500 feet.

The metamorphic complex in this part of Madison County, generally considered the Pony series, consists essentially of light and dark-colored gneisses containing much quartz, hornblende, and biotite in addition to feldspar. Some zones in the gneiss contain so much hornblende that they may be considered amphibolite, and other zones are essentially biotite mica. Many bodies of pegmatite cut the metamorphic complex, and small stringers of quartz-feldspar pegmatite are present in the area of bull-dozer cuts. The deposition of pegmatitic material is not conspicuous, probably because large bodies have not developed in this immediate locality. The main mass of the Tobacco Root batholith lies about four miles southward, but small granitic masses occur within three miles south and west. The layers of the metamorphic rocks dip 80 to 85 degrees northeast, and the pegmatite stringers commonly follow the layers. Folded quartzite, shale, and limestone of middle Cambrian age overlie the metamorphic rocks about half a mile north of the vermiculite deposits.

The vermiculite-bearing rock is in a zone of typical medium-grained schist about one-fourth mile wide. The schist is well layered, and in open cuts shows gneissic bands of quartz and feldspar, these layers being from an inch or two to perhaps a foot in thickness. The vermiculite occurs in similar layers, but their thickness may reach several feet. However, in the purest material grains of quartz and feldspar, and also garnet, may be disseminated through the vermiculite. All of the micaceous mineral does not show equal expansion, apparently some not having quite reached the "vermiculite stage" of alteration.

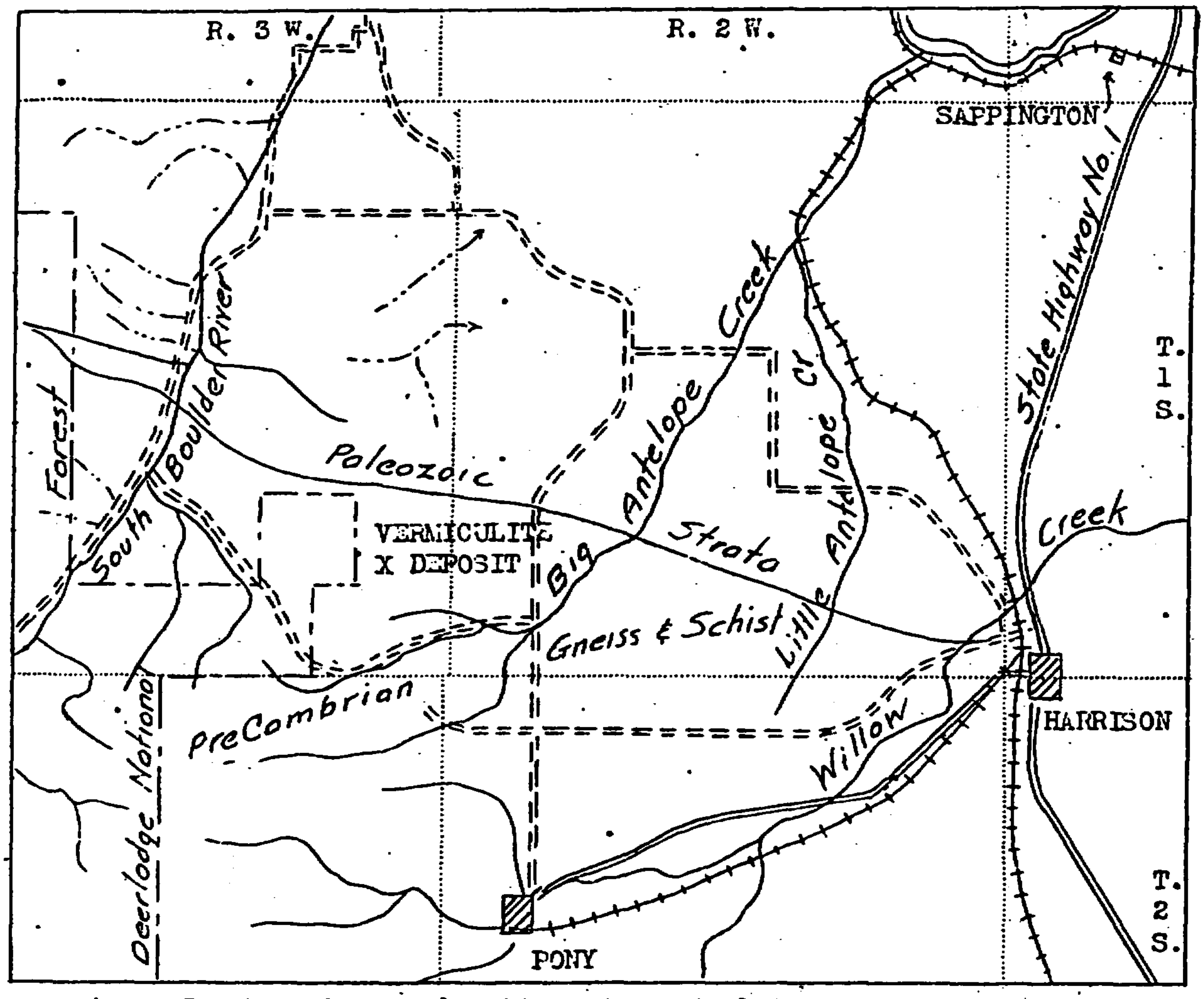


Figure 7.--Map showing location of vermiculite deposits near Pony.

The Pony vermiculite is fine grained, average size ranging from about 1/5 to 1/50 of an inch in diameter. The mineral plates may be 5 to 6 times as wide as they are thick. Hence the expanded material is fine grained, a condition which might limit its utilization to special purposes. The reserve is extremely large, and apparently vermiculite occurs in nearby areas not exposed by digging.

Mining operations could readily be carried on by open cut methods. The material mined would require concentration because of the large amount of undesirable minerals associated with the vermiculite, and this amount in some material may be half the volume. However, some zones of vermiculite are nearly pure.

Other areas of vermiculite-bearing schist have been reported south of Harrison, near Ennis, near Virginia City, and southeast of Dillon. They have not been opened extensively by digging, and detailed information concerning them is not at hand. Some of the material examined greatly resembles the material from the Pony deposit, and it is probable that all these occurrences are much alike. They lie in the extensive area of schists and gneisses comprising the metamorphic complex of southwestern Montana.

Mica-bearing Dike South of Bozeman

An unusual mica-bearing dike is present on Squaw Creek drainage 15 air-line miles south of Bozeman and about three miles east of U. S. Highway No. 191, which passes along Gallatin River. (See fig. 8, p. 36). The dike is one mile up a small tributary of Squaw Creek known as Mica Creek at a point where the gulch forks. The country rock is pre-Cambrian gneiss and schist, but it is cut in many places by light- and dark-colored dikes and sills, and by pegmatite dikes. A dark-colored igneous intrusion six miles south of Squaw Creek near Karst Kamp has altered into a commercial deposit of amphibole asbestos. The region is mountainous and heavily timbered.

The mica-bearing dike stands nearly vertical and strikes nearly due north up the nose of a steep-sided ridge lying between the two forks of Mica Creek. It can be traced for over 600 feet along the surface. The width of the body is variable, but near its southernmost exposure which is at creek level it appears to range from 10 to 20 feet in thickness. The dark-green to black micaceous mineral, considerably altered, is the essential constituent of the dike, and parts of the dike may be almost all micaceous; however dark-colored silicate minerals are also present and locally are dominant. Pegmatitic action shows in the form of small stringers of quartz and feldspar cutting the dike rock.

The micaceous material appears to be an altered biotite or hydrobiotite. Most of it is irregularly massed together in sheets (or books) less than one-half inch across, but sheets two inches or more across may be observed. The mica readily splits into thin sheets, but it is flexible rather than elastic as is the case with unaltered mica. The material upon being heated shows some expansion amounting to perhaps two or three times, but this amount does not warrant classifying it as a vermiculite.

The deposit has been opened by a short adit near creek level, and by several pits and trenches spaced at intervals along the outcrop. None of the material has been marketed, and there seems to be no demand for it at present. The deposit is of geologic interest, and it is illustrative of this type of dike which may be found elsewhere in western Montana.

PART IV. ASBESTOS

General Considerations

Amphibole asbestos has been produced in Montana on a commercial scale from deposits near Karst Resort south of Bozeman. Serpentine asbestos occurs near Cliff Lake, but has not been produced on a commercial scale. Occurrences of asbestos have been reported at Libby, and it is possible that unknown deposits of commercial size are present elewhere in Montana.

The value of asbestos lies in its unique ability to be separated into fine fibers, even as fine as 1/5000 inch across. Since asbestos is a rock-forming mineral these fibers are refractory (difficult to fuse), and are desirable for fire and heat insulation. The fibers are also acid resisting, and of course will not decay.

Asbestos, a name applied to a group of minerals, is broadly of the two different types, amphibole and serpentine, the latter being valued at about ten times the former. The fibers of the amphibole variety, also known as "brittle asbestos", tend to break and hence cannot be woven into cloth; but mixed with a binder, such as plaster of Paris, this type is excellent for the manufacture of fire-proof wall-board and shingles, for steam pipe and furnace coverings, and many other commodities.

Serpentine asbestos, also known as chrysotile, separates into fine strong silky fibers which can be spun into thread and woven into a flexible cloth. Such cloth is valuable for fire-proof clothing and gloves, for fire-proof curtains in theaters; but in particular for brake linings, clutch facings, and gaskets in automobiles for which most of it is used. Because of these characteristics it is much more valuable than amphibole asbestos, but good deposits of it are not plentiful. Serpentine asbestos is a hydrous silicate of magnesium; amphibole asbestos is a magnesium silicate containing some calcium, aluminum, or iron. A definite distinction must be made between the two kinds of asbestos.

Asbestos is easy to recognize. As it occurs in the ground it is a hard solid fibrous mineral commonly showing pearly luster. However, small pieces can be pounded easily into a fibrous mass resembling cotton-batting. Distinction between the two types can be made by fluffing the mineral and then rubbing between the fingers. Amphibole asbestos will develop a powdery mass, but serpentine asbestos will roll into a thread.

The two types of asbestos seldom are present in the same deposit. The common feature of all deposits is some degree of metamorphism, in most cases extreme. Serpentine asbestos may occur in altered basic igneous rocks, such as dunite or peridotite, or in altered dolomitic marble or limestone. About 90 percent of the worlds supply is derived from dunite or peridotite which have been altered first to serpentine. Amphibole asbestos may occur in altered basic igneous rocks, or in sedimentary rocks converted to schist or gneiss. Both types originate by deep-seated alteration of pre-existing rocks.

Deposits of minable asbestos in the United States are limited in extent. Deposits of chrysotile have been worked or explored in seven or more states, and amphibole asbestos in nine or more states; however, total United States production is only from 1 to 2 percent of the world supply, and this country is practically dependent on imports from other countries. Canada produces about 60 percent of the world supply, southern Africa and Russia being next in importance. Total world production normaly ranges from 400,000 to 600,000 tons per year, of which the United States imports over 50 percent.

Price of chrysotile asbestos ranges from $20 to $750 per ton, depending on grade, and of amphibole asbestos from $10 to $40 per ton. Length of fiber, as well as type, is important in determining utility and value.

Asbestos deposits near Karst

<u>Location and accessibility</u>: The amphibole type of asbestos has been mined and marketed from a deposit 32 miles southwest of Bozeman near Karst Resort on Gallatin River. Mining has been carried on in only one place, but asbestos shows at other places within 1500 feet both east and west.

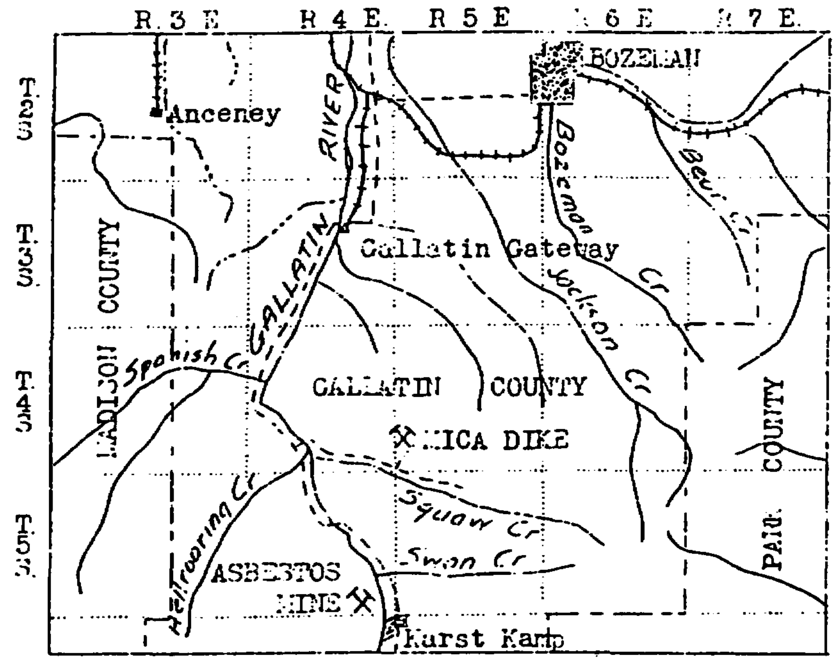


Figure 8.--Map showing location of Mica Creek deposit and the Karst asbestos deposit.

Karst is 22 miles south of Gallatin Gateway, a station on a branch line of the Chicago, Milwaukee, St. Paul, and Pacific Railway, and the nearest shipping point. U. S. Highway 191, which is oil surfaced, extends along Gallatin River past Karst. Elevation of Gallatin Gateway is 4900 feet and of Karst about 5700 feet above sea level. The area is mountainous. The Madison Range lies on the west side of Gallatin River, and the Gallatin Range on the east side. Gallatin Peak about 15 miles westward has an altitude of 10,967 feet. Gallatin River in this locality flows through a narrow steep-sided valley heavily timbered in most places.

The asbestos deposits lie 2000 to 4000 feet west of the highway and river on a steep mountain slope. They are about 1000 feet higher in elevation than the river. A side road crosses the river on a wooden bridge, and continues about 800 feet to a small mill and cabins. A bull-dozer road and a foot-trail lead up the slope to the mine, and a horse trail continues on into the mountains.

The deposits were discovered nearly half a century ago by Peter F. Karst who noticed the unusual mineral while hunting for deer. It is stated that about 600 tons of asbestos were hauled on horse back down the mountain slope and then hauled to shipping points in the next few years. Larger scale development did not proceed until 1935, nearly 40 years after discovery, when the Karstolite Company reopened the deposit by open-cut and began development. They produced a product called Karstolite used for wall and ceiling insulation. In 1938 the Montana Asbestos Company began an operation which continued for two years. An aerial tram was constructed, and the asbestos was milled and concentrated near river level, sacked, and then transported by truck to Gallatin Gateway, from where it was shipped by rail to markets. The property then remained idle until 1947 when the Interstate Products Company cut the bull-dozer road up the steep mountain slope, and prepared for commercial development.

General Geology: The rocks underlying the area of asbestos deposits, and for several miles around this area, are mainly a part of a complex series of banded and contorted gneisses and schists of early pre-Cambrian age. They are probably a part of what is known in Montana as the Pony series. Metamorphism is so far advanced that it is difficult to determine if these rocks were originally sedimentary or igneous, but it is probable that they were largely sedimentary. These rocks have been intruded by dikes or sills, and most of these intrusions in turn show alteration, although not all to the same degree as that of the containing rocks. Some dikes, which no doubt are to be associated with the Cretaceous-Tertiary intrusions of Montana, show no signs of alteration. Pegmatite dikes unaltered and undeformed also are present close to the asbestos deposits. Apparently there is more than one period of dike intrusion, and some dikes may antedate the intense metamorphism. The Gallatin Range east of the river is composed essentially of a thick series of Cretaceous or Tertiary andesite flows and breccias (volcanic material) many miles in extent. Landslides of a remote date have marred the steep slope between the asbestos mine and the river obscuring the underlying rock. They appear as roughly terraced areas 50 to 100 feet wide paralleling the face of the mountain, and they are timbered with large trees.

Geologic structure of the gneissic complex is obscure, but 3 to 4 miles north and south of Karst are major faults trending northwest whose displacement may be measured in terms of miles. In the immediate area of the asbestos deposits smaller faults cut the rocks apparently in an intricate pattern.

The asbestos occurs in small altered bodies of peridotite, apparently dikes composed essentially of amphibole. These bodies cannot be traced for any considerable distance due to soil and slide-rock cover on the steep timbered slopes, and also probably due to minor faulting. Since intrusion, alteration of the original rock has caused the development of numerous vein-like or stringer-like masses of fibrous amphibole from an inch to a foot or more in thickness which cut irregularly through the dark-colored igneous rock. Most "veins" stand nearly vertical, they strike from due north to N. 70° W., and many can be traced 10 to 20 feet in the face of the mine pit.

The pure asbestos has grown with its fibers, which may be a foot or more in length, practically at right angles to the walls of the containing rock. Most of the fiber is straight but some is curved, particularly at ends, as though bent by earth movement. The containing rock, although superficially appearing to contain no asbestos, is intergrown with disseminated fibers. In the main workings only asbestos and altered rock were observed, but about 350 feet southward clear slender grass-green crystals, probably actinolite, were observed with asbestos.

The percent of asbestos in the asbestos-bearing rock which was mined was not accurately determined. Estimates by workmen range from 30 to 50 per cent. Also the amount of development work at the time of visitation did not permit calculation of total reserves of asbestos-bearing rock, however several thousand tons were apparent at that time. Specific gravity of the asbestos ranges from 2.9 to 3.0, and its weight per cubic feet of unbroken rock is about 185 pounds. An analysis of the asbestos stated in terms of oxides of elements is shown on the following table, although of course practically all of these constituents are present in the form of a silicate mineral. Optical properties of the asbestos show it to have parallel extinction, low relief, and indices of refraction 1.67 or less. These various properties indicate that the mineral is the orthorhombic amphibole known as anthophyllite.

Chemical analysis of Karst Asbestos (per cent)
(Lewis and Walker, Butte, Montana)

SiO_2	56.0
Al_2O_3	5.8
FeO	8.9
CaO	1.2
MgO	26.0
Ign. loss (H_2O)	2.0

Development: The asbestos mine is essentially an open cut or pit approximately 50 by 100 feet in plan, but it has been cut into the steep slope as a series of irregular benches, the workings having followed the better grade of asbestos-bearing rock. "Veins" of asbestos show throughout all of the pit. About 30 feet below the level of the pit floor, and 40 feet southward a 100-foot adit has been driven so as to pass beneath the surface workings. The first 30 feet were in pegmatite, the next 40 feet were in asbestos-bearing rock, and pegmatite is at the northern end. Two faults which converge downward appear to be between the asbestos rock and the northern and southern bodies of pegmatite. A shaftn non filled, connected the adit and the pit. Sixty feet north of the pit is an unaltered vertical syenite dike trending northeastward. Immediately west and east of the pit are exposures of gneiss.

Fifteen hundred feet southeast of the open cut low down on the slope a short adit apparently driven into landslide material encountered showings of asbestos. Sixteen-hundred feet S. 75° W. of the cut and at about the same elevation "veins" of asbestos show in an area at least 40 feet by 75 feet, and short adits have been driven. The accurrence and the appearance of the asbestos in those adits and on the dumps in front of them is similar to t at in the main pit, however some material is more inflexible and does not fluff so readily. These occurrences indicate presence of asbestos-bearing rock in an area at least 3000 feet across.

Mining and Milling: In mine operation the mixed asbestos and rock were blasted in the open cut, loaded by hand into cars, and trammed about 60 feet to a bin. Some selective mining was practiced. In one part of the pit five vein-like bodies of asbestos totaling about three feet in thickness show in an eight-foot working face. More asbestos shows in other parts of the pit. A large dump of mixed asbestos and rock has developed in front of the pit, and much of this material is of milling grade.

An aerial tram, consisting of buckets suspended on a moving cable, carried the material about 1650 feet from the bin to a small mill situated 800 feet west of the river and 100 feet higher. Since the loaded buckets traveled down grade and the empty buckets up grade, no power was n eded to operate the tram, in fact brakes were needed. However, a gasoline motor was used to start the operation.

At the mill the material was crushed, and then passed through a hammer mill which caused the asbestos to fluff and the rock to crumble. The material was then introduced into an air classifier consisting of a rising column of air in a cone-shaped container. Fluffed asbestos ready for shipment was carried out by the air, and crushed rock fragments settled to the bottom and were removed. The asbestos was then sacked in paper bags and trucked to the railroad at Gallatin Gateway. In all, 1800 tons of asbestos reported to have been valued at $35 per ton f.o.b. Gallatin Gateway are said to have been marketed. Electric power for the mill and for lighting was generated by a small hydroelectric power plant on Moose Creek on the east side of Gallatin River, about 1500 feet northeast of the mill.

Serpentine Asbestos near Cliff Lake

Location and development: An occurrence of serpentine asbestos (chrysotile) about 50 miles south of Ennis has been explored, and an attempt was made to mine and mill the mineral. The deposit is in section 25, T. 12 S., R. 2 E. nine miles by road southeast of Cliff Lake Post Office in a deep rugged gulch tributary to Mile Creek. A graded dirt road leaves State Highway No.1 near the Post Office, crosses Madison River on a wooden bridge, and continues across terraced and rolling valley lands to about one mile of the mine where a mine road leads into the gulch. The deposit lies on the flank of a high rocky range facing Madison River valley.

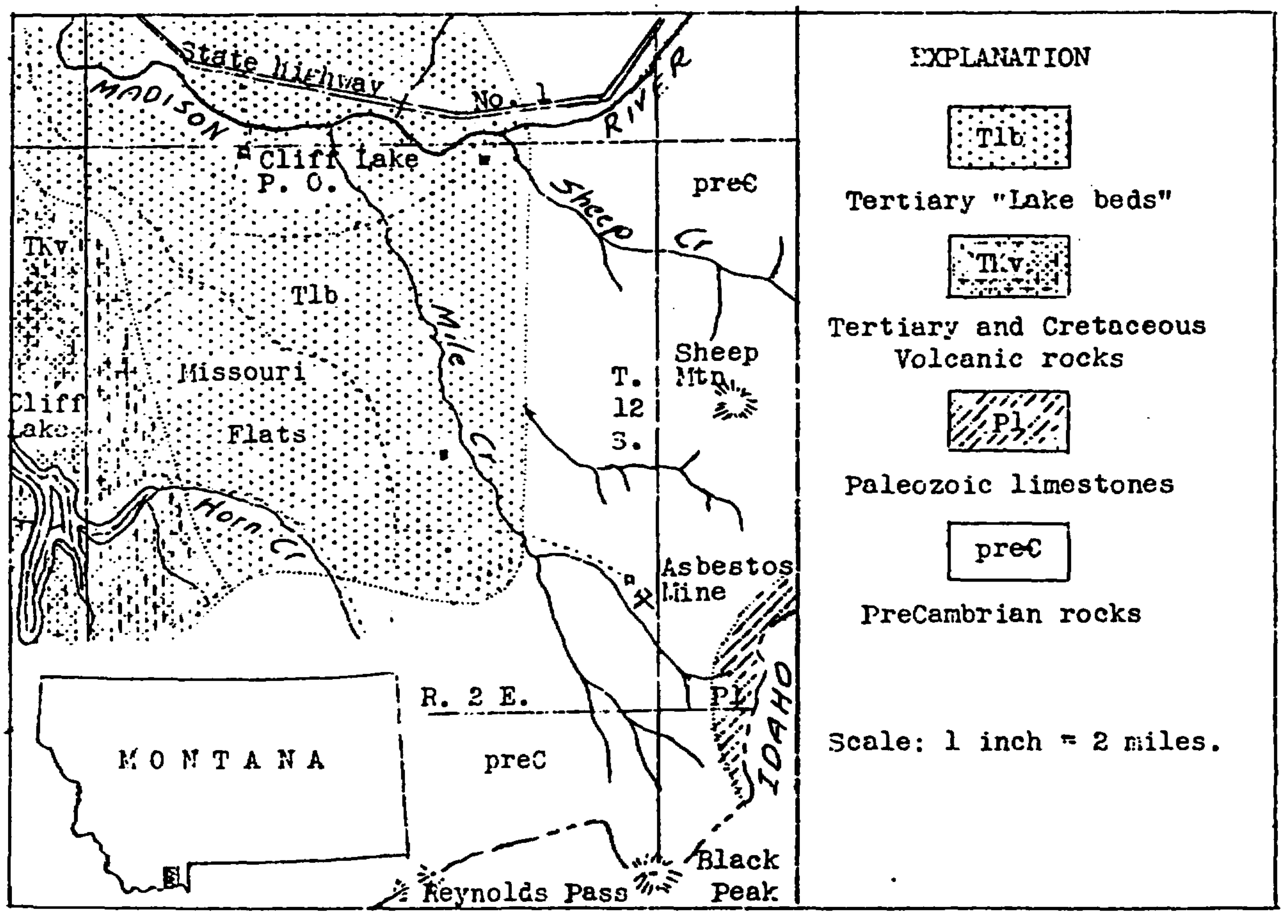


Figure 9.--Map showing location of Cliff Lake asbestos deposit, Madison County.

The deposit was discovered by Israel A. Hutchens about 1890. Shortly after 1900 the Idaho Montana Asbestos Company prospected it by driving an adit over 200 feet into the mountain. Commercial quantities of asbestos were not found. About 30 years later after reorganization and some prospecting, the Montbestos Company was formed. Large substantial buildings were erected, heavy and elaborate machinery both for mining and for milling was installed, and a renewed effort was made to find commercial deposits, and to separate the asbestos from the rock. The operation was unsuccessful, and in 1935 the machinery was taken away, and the property was abandoned.

In all about 500 to 600 feet of underground adits have been driven, and three large surface excavations besides small pits were made into the steep mountain slope. Milling operations included crushing, wet screening, and cone classificati some by means of air. Total amount of rock put through the mill was small.

Geology: The side of the mountain range in which the deposits lie is composed of marble, gneiss, and schist, possibly a part of the Cherry Creek series of early pre-Cambrian age. The rocks of this area do not closely resemble typical rocks of the Cherry Creek series, and they may be a part of some related pre-Cambrian series. However, the asbestos occurs in a thick marble member within which one- to five-foot zones of yellow-green serpentine were developed, apparentl following along planes of shearing. Bedding is steeply inclined or vertical, and shearing planes are inclined at about 40 degrees and cut bedding. A dark-colored igneous rock (gabbro) was intruded into the marble, and although not observed in outcrop near the pits, it was encountered in mine workings which extended into the mountain. No typical pegmatite dikes were observed. Much dirty-white quartz, pegmatitic in character, is present in the marble as thin irregular stringers roughly parallel to the shearing. Other minerals, particularly a fibrou amphibole, are abundant locally. Some of the marble appears gray because of included microscopic grains of magnetite.

The asbestos occurs in narrow veinlets cutting serpentine and marble. Most of the veinlets are from 1/16 to 1/2 inch in width, and they commonly extend four inches to a foot or two before pinching out. Numerous veinlets may occur in a zone of serpentine running roughly parallel to each other and to the zone. Some veinlets appear to cut pure marble, but there may have been massive serpentine present before the growth of asbestos. The fibers in the asbestos lie at right angles to the vein walls, and extend completely across the veinlets. The total amount of serpentine in proportion to marble is small, perhaps one or two percent, and the amount of asbestos in proportion to massive serpentine is probably equally as small. The failure of the mine appears to have been due mainly to the small amount of asbestos present; however, so far as known to the writer, no long fiber asbestos is present.

Asbestos near Libby

Amphibole asbestos occurs with vermiculite in altered dark-colored igneous rock (pyroxenite) near Libby. It accurs most abundantly in the northwestern part of the area, particularly on the spur north of Kearney Creek. As described by Larsen "several bodies . . . are dike-like or tabular in form and of different widths. The largest, as exposed by open cuts, appears to be 100 feet or more long and from a few feet to 14 feet wide .... Samples representing the different bodies show the amphibole to be mixed with 1 to 10 per cent of other minerals, chiefly vermiculite and unaltered pyroxene. In other places the country rock is particularly rich in amphibole. A sample across a width of 10 feet of the rock as exposed by a short tunnel contains, in round figures, 75 per cent amphibol 15 per cent of pyroxenite and apatite, and 10 percent of vermiculite. A sample representing another body 50 feet wide consists of 50 per cent amphibole, 30 per cent pyroxenite, and 20 per cent vermiculite."

The Libby amphibole asbestos related to (tremolite) works up into a fluffy mass similar to the general run of asbestos, although the fibers are weak and inelastic and break into short pieces. Weathering seems to have produced a softer type of fiber. Milling would be necessary to obtain a commercial product, and some trouble might be had in separating the vermiculite. No asbestos has been marketed from this deposit which is worked on a large scale for vermiculite. In general it may be said that the Libby asbestos deposits are of minor importance because of small tonnage and low quatity.

For a map of the area, and descriptions of the geology of this deposit, the reader is referred to the chapter on vermiculite in this report.

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Other Occurrences of Asbestos

Hand samples of asbestos, both amphibole and serpentine, have been picked up in western Montana and submitted to the Montana School of Mines for identification. Failure to expose large bodies of this material suggests that the deposits were small. With the large amount of igneous intrusion and metamorphism in this region, it is possible that commercial bodies still remain undiscovered. However, in western Montana every gulch has been prospected for metalliferous minerals during the past 80 years, and it would seem unlikely that so conspicuous a mineral as asbestos could be exposed in commercial deposits, and yet the deposits not be made known.

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